

Mount Nansen Dome Creek and Victoria Creek Surface Water Quality Evaluation and Preliminary Aquatic Effects Assessment

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The Mount Nansen Mine is a former gold and silver mine (60 km west of Carmacks, Yukon) that operated from 1996 to 1999 (Figure 1-1). The mine area, which consists of a mill area, open pit, waste rock dump and tailings impoundment, is classified as an Abandoned Type II site under the care of the Government of Yukon.

Recent (2014 and 2015) monitoring observations have identified increasing concentration trends for parameters of concern that include arsenic (As), cadmium (Cd), iron (Fe), manganese (Mn), and zinc (Zn). Elevated values for these parameters have triggered action as outlined by the Mount Nansen Mine Adaptive Management Plan (AMP) (SRL, 2015) as follows:

- 1. Notification and validation;
- 2. Preliminary identification;
- 3. Analysis and investigation; and
- 4. Response plan.

The first two components of the AMP have been implemented. Lorax Environmental Services Ltd. (Lorax) was retained to address components 3 and 4, as outlined in the scope of work submitted to Little Salmon Carmacks First Nation (LSCFN), Yukon, and Canada (the Parties) (Lorax, 2016a). The Lorax scope of work includes the following main tasks:

- Task 1 Tailings seepage collection pond water quality assessment of current and future conditions;
- Task 2 Dome and Victoria Creeks effects assessment of current and future conditions;
- Task 3 Tailings seepage collection pond water balance; and
- Task 4 Definition of conceptual response plan with supporting mitigation.

The following report, submitted by Lorax, includes data and discussion in support of Tasks 1 and 2, with Tasks 3 and 4 to be completed during the 2016 fiscal year. Specific objectives of this report are to:

- Define water quality trends evident for the various monitoring areas including (from upstream to downstream) upper Dome Creek, Tailings Pond, tailings impoundment groundwater, Tailings Seepage Pond, lower Dome Creek and Victoria Creek;
- Define the hydrologic and biogeochemical controls governing trends in water quality;



Figure 1-1: Mount Nansen Mine location map.

- Provide a preliminary aquatic resources effects assessment relating to current conditions in lower Dome Creek and Victoria Creek; and
- Provide recommendations for on-going water management, mitigation and monitoring.

Chapter 2 of this document describes current water quality conditions in project-area streams, and describes trends for key parameters. This assessment serves as the basis for a preliminary aquatic effects assessment (also provided in Chapter 2). An assessment of potential future water quality conditions is presented in Chapter 3 and is followed by a discussion of implications regarding the AMP response plan in Chapter 4. Monitoring recommendations are provided in Chapter 5.

In the surface water quality assessment below, current water quality conditions are described. As well, a preliminary aquatics resources effects assessment is provided. The assessment has been divided spatially into three zones: 1) mill area and upper Dome Creek; 2) tailings impoundment and lower Dome Creek; and 3) Victoria Creek. A detailed description of current water quality conditions was provided in the memorandum "*Mount Nansen Closure Plan – 2016 Water Quality Update*" (Lorax, 2016b), and is attached to this document as Appendix A. A summary of this latter report is provided below. Scoping of water quality parameters of concerned is defined by AMP event triggered events (SLR, 2015a) and was expanded to include other related parameters of interest (Lorax, 2016b). A summary of all data sources is provided in Appendix B, while sampling locations for surface water quality monitoring locations are shown in Figure 2-1.

2.1 Current Water Quality Conditions

2.1.1 Mill Complex and Upper Dome Creek

Time series data for DC-DX+105 (adjacent to the mill area and downstream of the Huestis workings) illustrate pronounced mine-related signatures with respect to major ions (SO₄, Ca and alkalinity) and several trace elements (Mn, As, Cd and Zn) (Appendix A). Inspection of the data to early 2016 indicate that contaminant levels cannot be linked to values in mill area groundwater wells. Rather, loadings are likely associated with localized, point-source inputs to surface waters from mine wastes proximal to the historic settling ponds as well as from the Heustis Adit. In terms of temporal trends, values for SO₄, Ca and alkalinity at DC-DX+105 have remained relatively constant since 2012. In contrast, the time series profiles for As, Cd and Zn show evidence of decreasing values since 2013 (as summarized in detail in Appendix A).

With respect to redox-related parameters in Upper Dome Creek, dissolved Fe and Mn show the highest values at DC-B. Flows at DC-B merge with seepage flows from the TSF upstream of DC-U (Figure 2-1). Given the circum-neutral pH conditions, the elevated levels of Fe and Mn are predicted to reflect the input of suboxic waters to the creek system, which may relate to both natural and mine-related inputs. Cadmium and Zn concentrations measured at DC-B are lower than values measured in discharge from the Tailings Seepage Pond (Seep) and downstream at DC-U and DC-R, indicating that upper Dome Creek contributes negligibly to the Cd and Zn signatures in lower Dome Creek (Figure 2-2).

Overall, the data for upper Dome Creek show that concentrations of parameters of concern are stable (*e.g.*, SO₄, Fe, Mn) or in some cases decreasing (*e.g.*, As, Cd and Zn). Further,



since upper Dome Creek is isolated from aquatic resources downstream of the tailings impoundment it was not evaluated in the aquatic resources effects assessment (Section 2.2).



Figure 2-2: Time series profiles for dissolved As, Cd and Zn for surface water stations in Upper Dome Creek (2009-2015 data). Note log scales on Y axes for Cd and Zn.

2.1.2 Tailings Impoundment and Lower Dome Creek

As summarized in detail in Appendix A, Tailings Pond waters have shown a progressive decline in salinity proxies (*e.g.*, SO4, Ca, TDS), several trace elements (Co, Cu and Ni) and NO₃-N since 2010 (based on visual interpretation of trends). In contrast, As, Cd, and Zn do not show any definitive inter-annual trends in recent years. For groundwater within the tailings impoundment, SO₄ shows evidence of increasing concentrations in some wells since 2010, and in some cases, these increases have been accompanied by commensurate increases in dissolved Ca and decreases in total alkalinity (Appendix A). Similarly, data for discharge from the Tailings Seepage Pond (Seep) show a trend of increasing concentration for TDS and SO₄ and Ca from 2011 to maxima in 2014 (SO₄ data shown in Figure 2-3). These data may indicate the early stages of enhanced sulfide oxidation within the tailings mass.

Inspection of redox-related parameters for the Seep show evidence of changing redox conditions within the tailings impoundment, as illustrated by a pronounced decrease in NO₃-N and an increase in the concentration of dissolved Fe since 2010 (Figure 2-3). Dissolved Mn also shows evidence of increasing concentrations in late 2014 and early 2015. These observations are indicative of a shift in redox pathways away from NO₃ reduction towards Fe/Mn-oxide reduction, in response to decreased NO₃-N availability. This conclusion is supported by groundwater data which also show increasing trends for dissolved Mn and Fe in some wells (as described in Appendix A).

Seepage Pond data for dissolved As show a similar pattern of increase to that of Fe (Figure 2-3), suggesting that the increased mobilization of As is related to the inferred transition towards more reducing conditions within the tailings impoundment. Dissolved Zn and Cd also show pronounced increases in Seep discharge in 2015-2016 (Figure 2-3). However, the Zn and Cd peaks do not correlate with Fe and As, suggesting other process contribute to the observed increases in the Seepage Pond. For example, these observations could relate to enhanced sulfide mineral oxidation and/or early onset of localized acid mine drainage, as illustrated by data for SO₄, Ca and alkalinity in groundwater.

In relation to discharge limits as defined by the Water Licence (Table 2-1), Seepage Pond waters show consistent exceedances with respect to both Fe and Mn (Figure 2-3). Infrequent exceedances have also been recorded for TSS. Note, however, that TSS is typically above Canada's metal mine effluent regulation (MMER) for TSS (15 mg/L). While MMER limits are only applicable to operating mines, they do provide an industry standard for end of pipe effluent discharged to the environment. Values for dissolved As, total Cd, and total Zn have consistently remained below their respect discharge limits (Figure 2-3).

2-5



Figure 2-3: Time series profiles for SO₄, total suspended solids, nitrate-N, Mn, Fe, As, Cd and Zn for the Seepage Pond (2010-February 2016 data). Discharge limits (Water License) and MMER limits shown for comparison.

Table 2-1:	
Tailings Seepage Pond discharge limits for key parameters as set out in Wate	e
License (QZ94-004)	

Parameter	Concentration
Suspended Solids	50 mg/L
Arsenic (dissolved)	0.15 mg/L
Cadmium (total)	0.02 mg/L
Iron (total)	1.0 mg/L
Manganese (not defined)	0.5 mg/L
Zinc (total)	0.30 mg/L

The SO₄ increase observed for the Seep between 2012 and 2014 coincides with increases in lower Dome Creek at both DC-U and DC-R (Figure 2-4). With respect to redoxsensitive parameters, the dissolved Mn peak in the Seep in 2014 is congruent with peak values at DC-U, although not evident further downstream at DC-R (Figure 2-4). In contrast, the rise in dissolved Fe concentrations in the Seep since 2010 is not manifested at any of the downstream stations (Figure 2-4), which can likely be attributed to the attenuation of dissolved Fe in close proximity to the tailings facility.

With respect to trace elements, the elevated values observed for As, Cd and Zn in the Seep in recent years are not clearly manifested at downstream stations, illustrating their likely co-attenuation with Fe/Mn-oxides. Fe/Mn-oxides will be expected to form within the oxygenated surface waters of Dome Creek. Many trace elements, including As, Cd and Zn, show a strong affinity for Fe/Mn oxide surfaces, and hence can be removed from solution via sorption pathways. Potential chemical instability of these secondary Fe/Mn oxides could result from exposure to suboxic conditions. This could potentially occur during ice-covered conditions or upon burial within stream substrates.

Overall, the data provide evidence of increasing concentrations of parameters of concern in Tailings Pond Seepage associated with redox processes and possibly acid-generating mechanisms. The potential for adverse effects to aquatic biota in lower Dome Creek is discussed in Section 2.2.2.

2.1.3 Victoria Creek

Downstream of the Dome Creek confluence, mine-related signatures are evident in Victoria Creek (Stations VC-R and VC-UMN) with respect to SO₄, Fe, Mn, As, Cd and Zn (Figure 2-5). Increases in SO₄ concentrations since 2010 cannot be linked to upstream inputs to Victoria Creek, as illustrated by the invariant values at DC-U (Figure 2-5). Rather, such increases are consistent with the higher values observed over the same time period in the Seepage Pond and lower Dome Creek, suggesting a tailings-related source. No discernible inter-annual trends are evident for other parameters of concern (*e.g.*, As, Fe, Mn and Zn) in Victoria Creek since 2010, with the possible exception of dissolved Cd,

Date	Sulfate	D-As	D-Cd	D-Fe	D-Mn	D-Zn	
4/20/2015	14	21	17	0.1	6.7	27	
5/5/2015	60	53	86	1.3	17	132	
5/13/2015	77	79	36	1.3	17	71	
6/16/2015	10	14	30	0.9	4.2	106	
7/14/2015	10	13	20	1.0	4.3	37	
8/19/2015	41	31	54	1.6	14	81	
9/15/2015	54	61	39	3.3	15	30	
10/14/2015	23	26	25	1.1	7.6	11	
11/17/2015	11	11	9.6	0.6	3.6	5.0	

Table 3-2:

Tailings Seep discharge ratio of model threshold versus current observations (2015 data). Values <2 have been highlighted to illustrate enhanced risk to aquatic receptors in Victoria Creek.

3.3 Water Quality Effects Summary

A preliminary aquatic effects assessment for lower Dome Creek (downstream of the Tailings Seepage Pond) and Victoria Creek downstream of the Dome Creek confluence suggests that Fe in lower Dome Creek may have a negative effect on sensitive benthic invertebrate species, particularly in areas near the tailings impoundment where precipitation of iron oxyhydroxides on the streambed is on-going (Section 2.2). In this regard, adverse effects to aquatic biota in lower Dome Creek may be associated with benthic smothering associated with Fe precipitation, TSS, and/or Fe in solution. In contrast, adverse effects to aquatic biota in Victoria Creek are not currently predicted.

which shows evidence of a possible decreasing trend. The potential for adverse effects to aquatic biota in Victoria Creek is discussed in Section 2.2.3.



Figure 2-4: Time series profiles for dissolved SO4, and dissolved Fe and Mn for Lower Dome Creek in comparison to Tailings Seepage Pond (2010-2015 data).



Figure 2-5: Time series profiles for dissolved SO₄, nitrate-N, alkalinity and various dissolved trace elements (As, Cd, Fe, Mn and Zn) for Victoria Creek downstream of Dome Creek confluence, both upstream (VC-UMN) and downstream (VC-R) of Minnesota Creek. Data compared to control site VC-U.

2.2 Preliminary Aquatic Resources Effects Assessment

2.2.1 Effects Benchmarks

In support of a preliminary effects assessment with respect to aquatic life, current water quality data for sites DC-R and VC-UMN were compared to effects benchmarks. As an initial step, water quality results were screened against generic long-term water quality guidelines for the protection of aquatic life (WQGs). Long-term water quality guidelines are concentrations which are derived to be protective of all species of aquatic life under continuous exposure. Concentrations that are below WQGs indicate that the parameter is unlikely to cause a negative effect to aquatic life. Concentrations greater than a WQG do not necessarily imply impact, but warrant an investigation (e.g., benthic monitoring) to determine if the concentration is high enough to cause a negative effect.

In the sections below, effects benchmarks are evaluated for the parameters of primary potential concern (SO₄, As, Cd, Fe, Mn and Zn). Both CCME guidelines (http://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines) and B.C. provincial guidelines (http://www2.gov.bc.ca/gov/content/environment/air-land-water/water-quality/water-quality-guidelines/approved-water-quality-guidelines) are considered. B.C. WQGs have relevance for guidelines that have recently been updated, and that are supported by more up to date toxicity information.

Sulfate

British Columbia is one of the few jurisdictions to have a WQG for SO₄ (BCMoE, 2013) and CCME has not derived a SO₄ guideline. The BC SO₄ guideline is hardness dependent, based on studies showing decreasing toxicity with increasing hardness (Table 2-2). No guideline for SO₄ has been recommended for hardness values greater than 250 mg/L due to a lack toxicological data at higher hardness levels. For the assessment of potential SO₄ toxicity in Dome Creek and Victoria Creek, it was assumed that the modifying effect of hardness plateaus at 250 mg/L, and that the WQG for the highest hardness range applies to water with hardness >250 mg/L.

Table 2-2:
BC Sulfate Water Quality Guideline for Protection of Freshwater Aquatic Life.

Water hardness (mg/L)	Sulfate guideline (mg/L)
Very soft (0-30)	128
Soft to moderately soft (31-75)	218
Moderately soft to hard (76-180)	309
Very hard (181-250)	429
>250	Need to determine based on site water

The BC SO₄ guideline is based on toxicity to early life stage rainbow trout, which likely has relevance to salmonids present to Victoria Creek (*i.e.*, Arctic Grayling). Other organisms are less sensitive to SO₄, and therefore the WQG may be overprotective for Dome Creek since post-mining fish sampling in Dome Creek has not confirmed fish presence (EDI, 2006).

Arsenic

The CCME and BC WQGs for As are both 0.005 mg/L. The CCME WQG is based on the sensitivity of a species of planktonic algae (*Scenedesmus obliquus*) which has been shown to exhibit reduced growth at an As concentration of 0.05 mg/L (CCME, 2001). A safety factor of 0.1 was applied to this lowest observable effect level to obtain the 0.005 mg/L aquatic life guideline.

Chronic toxicity end points for As were recently assessed for stream systems by Golder (2013). Specifically, the aquatic toxicity dataset used to generate the CCME (2001) As guideline was updated with data from more recent studies (Table 2-3). The updated dataset agrees with the CCME dataset in showing that algae are more sensitive to As than invertebrates or fish. The Golder (2013) report derived a chronic effects benchmark of 0.025 mg/L using a species sensitivity distribution (Figure 2-6) applied to the data in Table 2-3. Given the predicted absence of the planktonic alga *S. obliquus* in the creek systems, the 0.025 mg/L benchmark is specifically considered to be protective of the most sensitive organisms in the system (benthic algae), and is therefore inherently protective of less sensitive taxa (benthic invertebrates, fish and amphibians). In this regard, an As concentration of 0.025 mg/L is expected to afford a protective limit for aquatic life in both Dome and Victoria Creeks.

Cadmium

Both the CCME (CCME, 2014) and the BC (BCMoE, 2015) Cd WQGs have been recently updated. Both WQGs are hardness dependent. A major difference between the two guidelines is that the CCME guideline applies to total Cd while the B.C. guideline applies to dissolved Cd. The BC guideline was based on dissolved Cd for the following reasons:

- Dissolved Cd is the more bioavailable and ecologically relevant form;
- Concentrations of total Cd in BC waters are highly variable and depend on water flow and the associated concentrations of suspended sediment; and,
- Published toxicity tests have been conducted using dissolved salts, and as such are best represented as dissolved Cd.

Species	Taxon	Species Mean Chronic Value (mg/L)		
Algae				
Scenedesmus obliquus	green algae	0.010		
Melorisa granulata	diatom	0.075		
Ochromonas vallesiaca	golden algae	0.075		
Ankistrodesmus falcatus	green algae	0.100		
Lemna gibba	inflated duckweed	0.224		
Cryptomonas erosa	algae	0.225		
Chlamydomonas reinhardtii	green algae	2.25		
Anabaena variabilis	blue-green algae	2.25		
Scenedesmus quadricauda	green algae	5.49		
Lemna minor	duckweed	8.71		
Pseudokirchnerella subcapitata	green algae	25.0		
Microcoleus vaginatus	green algae	100		
Invertebrates				
Daphnia pulex	water flea	0.100		
Hyalella azteca	amphipod	0.581		
Gammarus pseudolimnaeus	amphipod	0.973		
Helisorna campanulata	snail	0.973		
Stagnicola emarginata	snail	0.973		
Daphnia magna	water flea	1.07		
Cyclops vernalis	copepod	1.38		
Ceriodaphnia dubia	water flea	1.42		
Fish				
Carassius auratus	goldfish	0.087		
Anabas testudineus	climbing perch	0.500		
Oncorhynchus mykiss	rainbow trout	1.76		
Pimephales promelas	fathead minnow	2.59		

Table 2-3: Arsenic chronic toxicity data compiled by Golder (2013) in support of derivation of a chronic effects benchmark.

The second bullet point is applicable to Dome and Victoria Creeks, which show large increases in total suspended sediment during spring freshet and following heavy rainfall events. Based on the above considerations, the effects assessment for Dome and Victoria Creeks emphasised the comparison of dissolved Cd levels to the BC WQG.

Iron

The BC WQG for Fe was used as the effects benchmark. The BC Fe guideline was updated in 2008 and was derived using more up to date toxicity information in comparison to the CCME guideline (derived in 1987). BC guidelines apply to both total Fe (1 mg/L) and dissolved Fe (0.35 mg/L).



Figure 2-6: Species sensitivty distribution for affects to freshwater aquatic life from arsenic (from Golder, 2013).

Manganese

CCME has not developed a WQG for Mn, and therefore the BC WQG was used as the effects benchmark. The BC 30-day guideline for Mn is hardness dependent, ranging from 0.70 to 2.4 mg/L over a hardness range of 20 to 400 mg/L.

Zinc

CCME is in the process of updating the Zn WQG, and a draft Zn WQG has been provided for public review (CCME, 2016). The CCME draft Zn guideline is based on a much more comprehensive data set than the BC Zn WQG, which was approved in 1999. Therefore, the draft CCME WQG was used as the effects benchmark for Zn. The draft long-term WQG is dependent on both hardness and pH. At pH 6, the CCME 30-day WQG ranges from 0.017 to 0.045 mg/L over a hardness range of 20 to 400 mg/L. At pH 8, the guideline ranges from 0.003 to 0.045 mg/L over the same hardness range.

2.2.2 Preliminary Effects Assessment - Lower Dome Creek

Dome Creek is a small creek that originates near the mill site. This drainage is diverted around the tailings impoundment and then flows through its natural channel to Victoria Creek. Channel width ranges from 0.30 to 0.65 m. There are a few shallow pools ranging

in depth from 0.05 to 0.21 m. It is predicted that most areas of Dome Creek freeze to substrate from November through April (EDI, 2009). No fish were captured during studies in 2005 and 2009 (EDI, 2009).

2015 water quality data for lower Dome Creek (site DC-R) for parameters of potential concern are shown in comparison to effects benchmarks in Figure 2-7. Note that due to frozen conditions in the winter months, there are no winter water quality data shown. Cadmium and Zn concentrations fell below WQGs in all 2015 samples, with the exception of the May T-Zn measurement which matched the guideline value. Conversely, As values were above the WQG (0.005 mg/L) and below the effects benchmark (0.025 mg/L) in all samples. Since As, Cd, and Zn show measurements consistently less than their respective effects benchmarks, adverse effects to aquatic biota in Dome Creek are not predicted from exposure to these parameters.

In 2015, SO₄, Mn and Fe, showed one or more concentrations above their respective WQGs (Table 2-4). Although the annual average SO₄ concentration has remained below the long-term WQG, the maximum SO₄ concentration measured in 2015 (572 mg/L) was 1.3 times greater than the WQG (429 mg/L). Given that the SO₄ guideline was derived using a safety factor of 2 applied to early life stage rainbow trout toxicity (Table 2-4), and that no fish are present in Dome Creek, it is unlikely that a SO₄ concentration up to 1.3 times the WQG will result in negative effects to the benthic invertebrate or periphyton communities in Dome Creek.

Table 2-4:
Parameters in lower Dome Creek (DC-R) with one or more measurements greater
than effect benchmarks.

Parameter	Number samples	# samples >benchmark	Benchmark (mg/L)	Annual average (mg/L)	Maximum (mg/L)	Maximum Exceedance Factor (mg/L)	WQG Safety Factor (mg/L)
Sulfate	8	3	429	408	572	1.3	2
Fe-T	8	7	1.0	2.1	3.6	3.6	1.7
Fe-D	8	8	0.35	0.8	1.4	4.4	10
Mn-T	8	2	1.9	1.6	4.5	2.4	4

Notes:

Benchmarks for sulfate and manganese based on a hardness of 300 mg/L (as CaCO₃).

Fe concentrations, both total and dissolved, were consistently greater than their WQGs in 2015. The T-Fe WQG was derived from a study that determined that long-term exposure to 1.7 mg/L resulted in a slight change to benthic invertebrate community structure. Given that the annual average T-Fe concentration at DC-R was 2.1 mg/L in 2015, it is possible that Fe has a negative effect on sensitive benthic invertebrate species in lower Dome Creek.



Figure 2-7: Time series profiles for SO4 and total/dissolved As, Cd, Fe, Mn and Zn for surface waters in Lower Dome Creek (DC-R) in comparison to effects benchmarks (2015 data).

The Fe in Dome Creek may originate from both natural and tailings-related sources. Specifically, elevated Fe values at DC-B are predicted to originate from suboxic flows that recharge the creek system (Appendix A). Such suboxic signatures could be related to flows that pass through naturally-occurring organic soils. Additionally, inputs from the tailings seepage pond (2015 annual average T-Fe = 13.5 mg/L) contribute to the Fe loading to lower Dome Creek. Oxidation of dissolved Fe in Dome Creek will result in the formation of Fe oxyhydroxides, which will precipitate out in the creek. Evidence of this includes visual observations of orange-coloured sediments on the stream bed of Dome Creek near the tailings impoundment. The effects of Fe precipitation on benthic communities in Dome Creek have not been assessed, but it is likely that the deposition of Fe-oxyhydroxides on the streambed, in conjunction with elevated Fe values in solution, may result in adverse effects to benthic invertebrate and periphyton communities. Field programs proposed for 2016 include assessment of the Fe precipitates and benthic community assemblages (described in Chapter 4).

In 2015, Mn showed values above the BC WQG in 2 of 8 samples. Rainbow trout represent the most sensitive organism in the literature used to derive the Mn WQG. The WQG was derived using a safety factor of 4 applied to the effect endpoint (growth) for rainbow trout exposed to Mn for 4 months (Table 2-4). Given that the maximum WQG exceedance factor for Mn was 2.4, and that no fish are present in Dome Creek, it is unlikely that Mn will have adverse effects to aquatic life in Dome Creek.

2.2.3 Preliminary Effects Assessment - Victoria Creek

In contrast to Dome Creek, Victoria Creek is fish bearing, hosting populations of Arctic grayling, slimy sculpin, and burbot (EDI, 2009). Victoria Creek flows year-round, and water quality samples were collected in each month during 2015. Freshet occurred in May in 2015, and caused a large increase in total suspended solids (TSS) concentration (Figure 2-8). The May TSS peak can be linked to concentration maxima in total metals associated with suspended sediments (T-As, T-Cd, T-Fe, and T-Zn) (Figure 2-9).

At VC-UMN, the only exceedances of effects benchmarks in 2015 occurred in association with the TSS maximum in May, reflecting elevated particulate metal levels during this time. This seasonal increase in TSS and total metals during freshet in Victoria Creek is a natural process that aquatic life in Victoria Creek experience on an annual basis and was observed upstream of Dome Creek. Overall, adverse effects to aquatic life in Victoria Creek are not predicted. This conclusion relates to: 1) lack of benchmark exceedances outside of freshet periods; 2) the natural occurrence of bench mark exceedances in association with freshet flows; and 3) decreased bioavailability of particulate-bound metals in comparison to dissolved metals.



Figure 2-8: Total suspended solids at Victoria Creek site VC-UMN during 2015.

2.2.4 Summary of Preliminary Effects Assessment

Water quality in lower Dome Creek has been influenced by the Mt. Nansen mine, with elevated levels observed for SO₄ and several trace elements. Examination of water quality data for 2015 shows that the potential for adverse effects to aquatic life in lower Dome Creek is unlikely from exposure to SO₄, As, Cd, Mn, or Zn. In contrast, Fe values in lower Dome Creek may have a negative effect to sensitive benthic invertebrate species, particularly in areas near the tailings impoundment where precipitation of Fe oxyhydroxides on the streambed in on-going. Concentrations of parameters of potential concern were below effects benchmarks in Victoria Creek downstream of Dome Creek (outside of freshet period), and therefore no mine-related effects to aquatic life in Victoria Creek are predicted.



Figure 2-9: Time series profiles for SO₄ and total/dissolved As, Cd, Fe, Mn and Zn for surface waters in Victoria Creek downstream of Dome Creek confluence (VC-UMN) in comparison to effects benchmarks (2015 data).

Estimates of future water quality and associated potential effects assessment is presented in the following chapter. A discussion of potential future water quality conditions and development of preliminary water quality thresholds for surface discharge from the Tailings Seepage Pond are presented.

3.1 Potential Future Water Quality

Scoping for this assessment as it pertains to location and parameters of interest is defined in Section 2. The water quality evaluation has shown increasing concentrations of As, Cd, Fe, Mn and Zn in surface discharge from the Tailings Seepage Pond in recent years (Section 2.1 and Appendix A). The data analysis has further identified two key processes that appear to govern the water quality of drainages emanating from the tailings facility: 1) redox conditions; and 2) sulfide mineral oxidation.

Redox processes appear to represent the dominant control on the concentrations of N, Fe, Mn, As, and TSS in Tailings Seepage Pond discharges. Increases in As, Fe, Mn and TSS concentration, for example, can be related to the enhanced reductive dissolution of Asbearing Fe- and Mn-oxide phases. This in turn can be linked to the depletion of nitrate through denitrification processes, and its decreased importance as an electron acceptor in redox pathways (*i.e.*, transition to Fe and Mn redox pathways). This new redox regime (*i.e.*, Fe and Mn redox pathways) is likely to persist over the long-term (multiple years or decades). This assumption relates to the essentially inexhaustible supply of reducible Fe and Mn oxide phases in the tailings. In this regard, rates of redox reactions can be expected to remain relatively constant, and therefore concentrations of Fe, Mn, As, and TSS in discharges from the Tailings Seepage Pond are not predicted to change appreciably in the future. This conclusion will not hold, however, if sulphide mineral oxidation and resulting acid generating processes continue to advance (discussed below).

Future rates of sulfide mineral oxidation and associated acid mine drainage (AMD) are more difficult to predict. Detailed static characterization has demonstrated that the tailings are potentially acid generating (PAG), with neutralization potential ratios (NPR) less than 1.0 (Lorax, 2010). If exposed to oxidizing conditions, therefore, such materials may produce AMD (Lorax, 2010). Characterization of dam fill indicates that the dam is generally non PAG with NPR values typically above 7.0 (AMEC, 2015). Zinc is an early indicator of AMD and elevated concentrations in Tailings Pond Seepage have been observed during winter baseflow periods in 2014/2015 and 2015/2016. As well, local evidence of early-stage AMD has been observed in the groundwater system as revealed by

elevated SO₄, Ca and Zn, and decreased alkalinity, in some wells. However, subsequent monitoring events will be required to confirm if these observations reflect acid-generation processes.

Results from kinetic testwork demonstrate that tailings within the impoundment are reactive, and have the potential to leach high concentrations of metals under acidic conditions (Lorax, 2010). Results of six kinetic cells (average of the final five weeks of the 50 week program) are summarized in Table 3-1 and include minimum and maximum concentrations. The results demonstrate a wide range in concentrations for the parameters of interest which speaks to the geochemical uncertainty. Maximum observed concentrations demonstrate the high potential for metal leaching under AMD conditions. Based on these observations, the development of AMD within the tailings impoundment is an unacceptable outcome. Under conditions of advanced AMD, rates of contaminant release will far outweigh those associated with redox-related processes.

Table 3-1:Maximum and minimum values for pH, sulfate and trace elements of interest inleachate from Mt. Nansen tailings humidity cells (based on average data for the
final five weeks of program). Data from Lorax, 2010.

Date	рН	Sulfate	D-As	D-Cd	D-Fe	D-Mn	D-Zn
Units	units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Maximum	2.2	2,672	34.6	0.36	962	1.5	16.2
Minimum	7.9	82	0.044	0.0012	0.0026	0.012	0.042

Predicting the timing of AMD is difficult; however, examination of past water management practices provides some insight. Beginning in 2005, water was discharged seasonally from the Tailings Pond due to improved water quality. After this time, water levels were kept at a minimum in the pond to help mitigate geotechnical risks associated with concerns over dam stability. The changes in water level in the Tailings Pond are clearly illustrated in Figure 3-1, which shows images for 2005 and 2010. Following these changes to water management practices in 2005, a greater proportion of tailings within the impoundment have been exposed to oxygen, allowing for enhanced sulfide oxidation within the unsaturated materials. This enhanced oxidation regime, which may lead to AMD, has been on-going for approximately ten years.



Figure 3-1: Pictures of flooded tailings impoundment (left, 2005) and drained tailings impoundment (right, 2010).

Development of full-scale AMD takes time. While tailings within the impoundment are no longer fully flooded, they will contain residual water content which will limit the ingress of oxygen. As a result, oxidation processes will likely be limited to the surface of tailings within the impoundment. However, as long as an extensive water cover is not maintained within the impoundment, AMD will continue to be an emerging risk. Regular monitoring of tailings solids within the impoundment (*e.g.*, rinse pH) along with routine monitoring of groundwater wells and piezometers will provide further insight on the potential emergence of AMD. Specifically, the development of acidic conditions in tailings groundwater can be expected to be initially localized in extent, and captured by a limited number of monitoring wells. Overall, the uncertainty in the time scales of AMD development preclude accurate predictions of future water quality.

3.2 Modeled Thresholds for Tailings Seepage Pond

Given the uncertainty in the time scales of AMD for the tailings impoundment, the ability to predict future water quality is greatly limited. As an alternative means to address water management planning for the site, a water balance and water quality model was developed to define water quality thresholds in Tailings Seepage Pond discharges that would result in exceedances in Victoria Creek water quality benchmarks (Water quality benchmarks are defined in Section 2.2.1). This inverse model is based on the protection of aquatic receptors (periphyton, benthos and fish) in Victoria Creek, and the assumption that aquatic biota in Dome Creek (periphyton and benthos) is a lower priority. While this assumption is consistent with the status quo, it may change as the assessment progresses and points of compliance are established for the project. Specifically, the importance of aquatic resources and the potential for guideline compliance in Dome Creek requires further discussion. The

definition of compliance points and associated water quality guidelines or benchmarks will ultimately form the basis for establishing water quality limits for surface discharge from the Tailings Seepage Pond.

Given the above, a model was specifically constructed to provide a point of comparison for potential effects in Victoria Creek, in that the results quantify a reasonably conservative upper water quality limit for surface discharge from the Tailings Seepage Pond. Thresholds defined through this modelling process are not intended to support the permitting of discharge limits, and are unlikely to be approved as such. Model results will also be used to identify key parameters of concern for fish bearing habitat in Victoria Creek.

Key assumptions of the model include the following:

- The Victoria Creek water quality model covers the period from April through November and excludes winter months (*e.g.*, November through March). While winter periods may be of importance due to limited dilution, field observations from EDI indicate that Dome Creek is frozen to ground during the winter period, and hence no surface water quality data are available. These observations suggest a winter connection between discharge from the Tailings Seepage Pond and Victoria Creek does not exist, as supported by Victoria Creek water quality observations from during the winter low-flow time period.
- The model was based on: 1) 2015 water quality data for the Tailings Seepage Pond and Victoria Creek (VC-UMN); 2015 flow data for Seep discharges and flow data for lower Dome Creek obtained from the hydraulic wier at Station DC-U due to higher quality flow measurements at this location in comparison to DC-B and DC-R.
- Due to the assumed no-flow conditions in lower Dome Creek from December through March, threshold values for the Tailings Seepage Pond were not caluclated (not applicable).
- Model results were calibrated to sulfate concentrations as sulfate is relatively nonreactive and conservative relative to other parameters of concern, namely As, Fe, and Mn.
- Dome Creek flows were increased by a factor of 2.5 in order to match maximum observed sulfate concentrations in Victoria Creek, which occurred in April. This flow factor was applied to all months and provided an added layer of conservatism in model results.

• Conservative behaviour is assumed for all parameters. In other words, threshold values developed for the Tailings Seepage Pond do not account for any attenuation that may occur in lower Dome Creek. This is a highly conservative assumption, as water quality observations show evidence of attenuation with respect to As, Cd, Fe, Mn and Zn.

Model results are illustrated in Figure 3-2 and are compared against current observations and historic water license discharge limits. Modeled thresholds are generally much higher than current observations for all parameters of concern with the exception of Fe.

For further comparison, modeled thresholds were calculated as a ratio against current observations (presented in Table 3-2). Ratios ≤ 1 are expected to yield concentrations in Victoria Creek that may exceed aquatic life benchmarks defined in Section 2.2.1. Values <2 have been highlighted in Table 3-2 as parameters at risk of exceeding the water quality benchmark in Victoria Creek. Note that only Fe is flagged as an at-risk parameter. As outlined above, these inverse model predictions do not consider the potential for Fe attenuation in lower Dome Creek downstream of the Tailings Seepage Pond. This factor serves to reduce the overall risk for aquatic resources in Victoria Creek.

Ratios for SO₄, As, Cd, Mn and Zn are considerably higher than those for Fe (Table 3-2). None of these parameters show ratios <2. Given that Mn and Zn are expected to show lower rates of attenuation in lower Dome Creek (as compared to Fe), these parameters must also be considered to represent important parameters for water quality management in Victoria Creek.

Overall, the results of the loading model exercise illustrate that Fe, Mn and Zn represent the primary parameters of concern for water quality management in Victoria Creek. The results specifically imply that for any further increases in tailings-related loadings to Dome Creek, these parameters pose the greatest risk for exceedances of aquatic life benchmarks in Victoria Creek. As such, Fe, Mn and Zn can be viewed as limiting parameters.

Based on redox-related processes, the concentrations of As, Fe, Mn and associated TSS are not likely to increase substantially. In contrast, the potential for AMD poses a higher risk of imparting benchmark exceedances in Victoria Creek. Note that maximum concentrations observed in tailings humidity cells (Table 3-1) are well above modelled thresholds (Figure 3-2). These results demonstrate that the potential for AMD presents an emerging risk to Victoria Creek water quality.



Figure 3-2: Modeled Tailings Seepage Pond discharge concentrations (Threshold) that would exceed WQ guidelines in Victoria Creek for key parameters (SO4, As, Cd, Fe, Mn and Zn). 2015 observations (Current) and Discharge Limits shown for comparison. Threshold values were not calculated for months with no measurable flow in lower Dome Creek (December through April).

In support of developing a rationale for water quality compliance and water management decision-making, the following activities and workshops were conducted with the Parties. The outcome of these workshops provides context for the development of a Response Plan as part of the AMP framework, as outlined in Section 1.

- A water quality and biological effects monitoring program was proposed in support of defining compliance and aquatic effects assessment (Lorax, 2016a);
- A workshop was held at YG, AAM (11 May 2016) to discuss work completed to date (Lorax, 2016b) including water quality effects, preliminary effects assessment, potential mitigation outcomes, and biological effects monitoring.
 - During the workshop AAM indicated its intention to obtain a water use license to authorize discharge from the Seepage Collection Pond.
 - Implications for permitting and managing water quality within the context of Yukon regulations were discussed.
 - Further feedback from the Parties was required to resolve the path forward with respect to compliance in support of developing a response plan.
- A water quality and compliance workshop was held at YG, AAM (8 July 2016) to discuss work completed to date (as reported through Section 3 of this report) and to discuss water quality objectives, effluent standards, and compliance, and identification of AMP response measures. Key outcomes from the workshop are summarized below:
 - LSCFN views Lower Dome Creek (from road to Victoria Creek) as potential habitat and potential source of nutrients for fish in Victoria Creek that should be protected. Implies that CCME should be met in the longterm.
 - Phased approach for care and maintenance to closure continual improvement.
 - Reclamation and closure objectives must also address water quality considerations in Upper Dome Creek.
 - Water quality compliance relative the discharge from the Seepage Collection Pond was proposed as follows:
 - Primary point of compliance determined at sampling location SEEP.

- WQ discharge limits as necessary to meet industry standards (e.g., MMER including TSS) and CCME in Lower Dome Creek (e.g., Fe and As).
- Surveillance Monitoring: Lower Dome Creek (DC-R or below)
 - WQ monitoring and comparison to CCME;
 - Biological monitoring to establish baseline, evaluate effects, and inform management/mitigation.
- Secondary Compliance: Victoria Creek (VC-UMN)
 - WQ monitoring and comparison to CCME;
 - Biological monitoring to establish baseline, evaluate effects, and inform management/mitigation.
- Mitigation would be required in order to meet T-Fe and TSS limits as defined above.
- Biological monitoring required to evaluate effects on aquatic resource. Monitoring is most relevant to Lower Dome Creek and Victoria Creek.

4.1 Adaptive Management Plan – Response Plan

Response Plans for the two events triggered in the AMP (SLR, 2015b) are provided below.

Event 1: Dome Creek WQ (DC-D1b) - total zinc in Upper Dome Creek

- Historic observations above threshold;
- Values are currently below the threshold but consistently above CCME guideline;
- Water quality trend is decreasing over time;
- Elevated concentrations are localized to within vicinity of mill and do not persist downstream (to DC-U1/U2 or DC-B);
- Upper Dome Creek identified as surveillance monitoring location.

Event 1 Response Plan

- Upper Dome Creek identified as surveillance monitoring location;
- Care and Maintenance:
 - Continued monitoring to confirm WQ trends do not increase and to confirm that observed local effects remain within Upper Dome Creek and do not migrate downstream to Lower Dome Creek;

- Low-flow survey recommended to confirm point source for elevated Zn (e.g., Huestis Adit) and identify point-source location for continued monitoring and to inform Reclamation and Closure;
- No further action recommended / warranted;
- Reclamation and Closure:
 - Further action expected to address water quality considerations in Upper Dome Creek.

Event 2: SEEP WQ

- Arsenic, Fe and Mn triggers exceeded with increasing trends;
 - Trends appear to have stabilized (Section 2.1);
- Cadmium and Zn below triggers but with increasing trends;
- T-Fe exceeds historic discharge limit;
- TSS values are associated with T-Fe and exceed industry standards (e.g., MMER);
- T-Fe and T-As exceed CCME in Lower Dome Creek (DC-R);
- T-Mn is typically below CCME in Lower Dome Creek (DC-R).

Event 2 Response Plan

- Lower Dome Creek identified as surveillance monitoring location;
- Care and Maintenance:
 - Mitigation recommended as necessary to meet industry standards in discharge (e.g., TSS) and to meet CCME in Upper Dome Creek (T-As and T-Fe);
 - Continued monitoring to confirm WQ trends do not increase further for parameters that appear to have stabilized (As, Fe, Mn);
 - Establish new trigger as 95th percentile of 2014 to 2016 data;
 - Special consideration of increasing Cd and Zn trends suggest potential early onset of AMD;
 - Continued monitoring and review of SEEP, tailings pond, and groundwater WQ recommended;
 - Establish new trigger as 95th percentile of 2014 to 2016 data;
 - If new trigger is exceeded, develop tailings survey and monitoring program to identify if early onset of AMD is occurring;
- Reclamation and Closure:
 - Further action expected to address water quality considerations in Lower Dome Creek.

Monitoring recommendations include the following:

- Commence environmental effects monitoring (EEM) in Dome and Victoria Creeks (Lorax, 2016a). EEM is recommended define baseline conditions as it relates to aquatic biological effects within the context of affected water quality and within the context of water quality changes (e.g., potential degradation and/or potential improvement following mitigation) during care and maintenance and/or through reclamation activities.
 - o A modified Before-After Control-Impact (BACI) benthic invertebrate community monitoring program is recommended to serve as an effective threshold effects monitoring tool for Dome Creek and Victoria Creek. In overview, the BACI approach entails the tracking of spatial and temporal changes in key benthic invertebrate community endpoints at mine-exposed and comparable reference areas. In combination with water quality, the evaluation of temporal changes in the selected benthic endpoints at mineexposed areas relative to those at reference areas is used to define thresholds for management action. The recommended program would be consistent with standard Environmental Effects Monitoring (EEM) implemented to satisfy Metal Mining Effluent Regulations (MMER), and would incorporate the use of Critical Effect Sizes (CES) to define effects thresholds.
 - Although quantitative benthic invertebrate community information with sufficient taxonomic resolution has been collected at Dome Creek and Victoria Creek historically (*i.e.*, ELR 2014), a suitable reference area for Dome Creek has not been identified nor sampled. Further, sample replication has not been sufficient to date to support a BACI approach. Overall, it is recommended that annual sampling be conducted in the first three years (e.g., 2017, 2018 and 2019) to establish a 'baseline' from which to track changes in existing conditions, with subsequent sampling conducted on a three to five-year frequency thereafter, depending on the findings of the most recently conducted survey. Dry Creek is proposed as a potential reference area for Dome Creek. Confirmation as to the suitability of Dry Creek as a reference site will be assessed through a site visit in year 1 of the program.

- Dissolved organic carbon (DOC) should be added to the parameter list for surface water samples collected from lower Dome Creek (DC-U and DC-R) and Victoria Creek. DOC is relevant to evaluating toxicity for Zn and is a modifying parameter for the draft CCME guideline.
- A winter flow and water quality survey of lower Dome Creek should be conducted to confirm observations made by EDI that a direct, surface water connection does not exist between the Tailings Seepage Pond and Victoria Creek. This is an important assumption for the water balance and surface water quality model and effects assessment for Victoria Creek. Further discussion with Yukon and EDI are warranted to gain a better understanding of this assumption and any related uncertainties and associated risks.
- Based on the above, discharge from the Tailings Seepage Pond is presumed to freeze in lower Dome Creek over winter months (November through March) and then discharge to Victoria Creek during the spring thaw. A focused monitoring plan may be required to gain a better understanding of these processes and their potential effects on Victoria Creek surface water quality.
- Repair monitoring well MW09-01. This well is within the tailings impoundment and may be providing early evidence of AMD. Water quality results show decreasing pH and increasing Cd and Zn; however results must be interpreted with caution due to observed well damage resulting in possible contamination from tailings and tailings pond water.
We trust that this memorandum meets your expectations at this time. Please contact the undersigned with any questions or comments.

Respectfully submitted,

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Appendix A: Surface Water Quality Assessment

TECHNICAL MEMORANDUM



То:	Bill Slater and Fred Green	Date: 20 Sept 2016
Cc:	Patricia Randell, Erik Pit, Emilie Hamm, Chris Dixon, Jason Berkers, and Paul LePage	Project #: A399-1
From:	Alan Martin and Justin Stockwell (Lorax Environmental Services Ltd.)	
Subject:	Mount Nansen – 2016 Water Quality Update – FINAL	

1.0 Introduction

The following memorandum provides a preliminary assessment of current water quality conditions at the Mt. Nansen Mine. Emphasis is placed on recent water quality trends (since 2010) in Dome Creek and Victoria Creek. Surface water sampling locations are shown in Figure 1. Groundwater sampling locations are shown in Figure 2.

The purpose of this memorandum is to provide a preliminary assessment of surface water and groundwater conditions at Mt. Nansen, as defined in Task 1 of the project scope of work (Slater Environmental, 2015). The results of this preliminary assessment will inform the scope and approach from which the remaining tasks of the Mount Nansen water quality review and aquatic risk assessment will be completed.

2.0 Water Quality Assessment

The water quality assessment has been divided spatially to assess the influence of the various contaminant source areas. In this regard, the assessment is presented for the following areas, from upstream to downstream:

- Mill Area and Upper Dome Creek;
- Tailings Facility (Tailings Pond, Tailings Area Groundwater, Seepage Pond);
- Lower Dome Creek; and
- Victoria Creek.

2.1 Mill Area and Upper Dome Creek

To assess the cumulative effect of contaminant sources associated with the mill site and waste rock, water quality for upper Dome Creek (up-gradient of the Tailings Pond) was assessed through inspection of data collected since 2010 for the following locations (listed from upstream to downstream):

• DC-DX: Dome Creek upstream of mine-related influences;

- DC-DX+105: Dome Creek adjacent to the mill area and downstream of the Huestis Workings;
- DC-D1: Downstream of mill area, upstream of D1B. May not capture all loadings from mill area and waste rock (data collected up to May, 2013);
- DC-D1b: Downstream of D1 (data for May 2012 to December 2015);
- DC-U1, DC-U2: South and north forks of Dome Creek, respectively, approximately 300 m upstream of tailings pond (data for May 2012 to November 2013); and
- DC-B: Tailings diversion channel downstream of all mill and waste rock loading areas (2014-2015 data).

At the upstream control location (DC-DX), time series profiles for major ions (Figure 3) and trace elements (Figure 5) show generally stable seasonal cycles, with pronounced minima observed during freshet. In contrast, the data for dissolved Mn and Fe at DC-DX show episodic spikes in concentration that are not observed for other parameters.

Long-term trends in Upper Dome Creek are not easily discerned given the relative lack of longterm time series data for a single location. Downstream of mine-related influences, DC-DX+105 shows the longest period of record for water quality monitoring (April 2012 to present). This site is the uppermost mine-impacted water quality sampling location on Dome Creek, and is located adjacent to the mill area and downstream of the historic Huestis Workings. Time series data for DC-DX+105 illustrate pronounced mine-related signatures with respect to major ions (SO₄, Ca and alkalinity; Figure 3) and several trace elements (Mn, As, Cd and Zn; Figure 4 and Figure 5). The magnitude of the elevated Zn concentrations at DC-DX+105 is not persistent across the drainage and could not be linked to Zn values in mill-area groundwater wells (SLR, 2015b). As described in Lorax, 2010, elevated Zn concentrations are likely associated with localized, pointsource contamination associated with mine waste proximal to the historic settling ponds and potentially associated with adit-related seepage inputs to the surface water system.

In terms of temporal trends, values for SO₄, Ca and alkalinity at DC-DX+105 have remained relatively constant since 2012. In contrast, the time series profiles for As, Cd and Zn show evidence of decreasing values. Dissolved As, for example, shows a dramatic drop in concentration in 2013, while Cd and Zn show more gradual and congruent declines over the period of record (Figure 5).

Downstream of DC-DX+105 at DC-D1b, major ions (e.g., SO₄ and Ca) show generally higher concentrations, reflecting additional mine-related inputs upstream of this location (Figure 3). These major ion signatures show evidence of further increases at DC-B, possibly indicating the influence of waste rock drainages. In contrast to the major ion parameters, concentrations of As, Cd and Zn show progressive decreases in concentration from upstream (DC-DX+105) to downstream (DC-B). The data for dissolved Cd and Zn, for example, show strong parallels,

illustrating that similar processes govern their remobilization and attenuation within Upper Dome Creek (Figure 5). For both parameters, the highest values are observed at DC-DX+105, with progressively lower values occurring with distance downstream to minima at DC-B. Dilution may play a role in the observed decrease as flows increase by roughly a factor of 10 between the two sites, however other mine signatures (e.g., SO₄ and Ca) show increasing trends with distance downstream (Figure 3). Based on these combined observations, the decrease in Cd and Zn between DC-DX+105 and DC-B is interpreted to reflect the attenuation processes along the creek system flowpath and is consistent with the data and interpretations provided in Lorax (2010) and SLR (2015b). The exact nature of the attenuation processes has not been defined, but likely include to some degree, adsorption/co-precipitation with Fe/Mn oxides, and possibly adsorption to organic substrates.

The magnitude of attenuation in Lower Dome Creek is significant, with values for As, Cd, and Zn at DC-B being very similar to background ranges observed at DC-DX (Figure 5). The concentrations measured at DC-B are also lower than values measured in the Tailings Seepage Pond and downstream at DC-U and DC-R, indicating that Upper Dome Creek contributes negligibly to the Cd and Zn signatures in Lower Dome Creek.

With respect to redox-related parameters, dissolved Fe and Mn show the highest values at DC-B. Dissolved Fe and Mn are not stable in neutral, aerated waters. Given the circum-neutral pH conditions, the elevated levels of Fe and Mn are predicted to reflect the input of suboxic (reduced) waters to the creek system (Figure 4).

2.2 Tailings Facility

Current water quality conditions for the tailings facility were examined with respect to the Tailings Pond, tailings area groundwater, and Tailings Seepage Pond.

Tailings Pond

Major ion concentrations in the Tailings Pond show a consistent seasonal pattern of minima during freshet (typically May), and increasing over the summer/fall/winter to maxima in the late winter period (April) (Figure 6). Superimposed on this seasonal cycle is a trend of decreasing major ion values since 2010, with both the annual minima and maxima generally showing lower values over time. Tailings pond pH values have remained stable (most values 7.2<pH<8.2). With respect to redox-related parameters, data for dissolved Fe, Mn, nitrite (NO₂-N) and ammonia (NH₃-N) show variable values, with no discernible inter-annual trends (Figure 7). In contrast, nitrate (NO₃-N) has shown a trend of declining concentrations since 2010, with all values in 2015 being <0.2 mg/L.

Trace element data for the Tailings Pond show mixed trends (Figure 8). Dissolved Co, Cu and Ni, for example, show generally decreasing concentrations since 2010. In contrast, As, Cd, and Zn do

not show any definitive inter-annual trends, with the exception of decreasing annual minima since 2010 (Figure 8). Chromium shows a pronounced decline in concentration beginning on April 17, 2013. This date coincides with decreases for other trace elements (Pb and Se) and NO₂-N, as well as a transition to higher detection limits for chloride, thiocyanate and cyanate. These observed changes may reflect a systemic analytical change (e.g., laboratory, instrument or methodology change) and are assumed to not be related to changes in the natural environment.

Tailings Area Groundwater

Water quality data for groundwater wells in the tailings facility are shown for major ions and pH (Figure 9), trace elements (Figure 10) and redox-related parameters (Figure 11). In general, major ions show seasonal and spatial variability. Data from piezometer MP09-12 are generally interpreted to be representative of background conditions and are shown in bold for comparison to other locations. With respect to major ions, SO₄ shows significant temporal variability with some evidence of increasing concentrations at MW09-1, MW09-2, and MW09-22. Data from MW09-1 should be viewed with caution, however, as the well head is reportedly cracked at surface (Hemmera, 2016) and likely has been contaminated by near-surface tailings and/or pond water. Possible SO₄ increases are evident at MW09-22, which shows a trend towards higher values in 2014 and 2015 (809 to 1990 mg/L) in comparison to values in 2009 and 2011 (70 to 156 mg/L).

Increases in SO₄ concentration as a result of sulfide mineral oxidation may be expected to also show increases in the levels of calcite neutralization products (e.g., Ca), and decreases in porewater, alkalinity, and pH. Indeed, the increases in SO₄ in MW09-22 are accompanied by commensurate increases in dissolved Ca and decreases in total alkalinity (Figure 9), suggesting the SO₄ additions may reflect the early stages of enhanced sulfide oxidation within the tailings facility, however the evidence for this is limited. Possible pH depression may also be evident at MW09-22, which shows a trend towards lower values in 2014 and 2015 (6.3 to 6.7) in comparison to values in 2009 and 2011 (6.9 to 7.4). Similar increases in dissolved Ca are observed at MW09-21, although alkalinity and pH values remain relatively stable. MW09-1 also shows pronounced increases in the concentrations of both dissolved Cd and Zn in 2013-2015, with 2015 maxima of 0.03 mg/L and 3.0 mg/L, respectively (Figure 10). Repair of MW09-1 and continued monitoring will be required to confirm if these measurements represent a change in porewater chemistry or an artifact of well disrepair and tailings pond contamination.

Overall, the data trends described above may indicate the transition towards acid generating conditions within the tailings mass. However, the data do not allow for definitive conclusions given the subtle changes in groundwater values. A transition towards acid generating conditions could result from: 1) depletion of neutralization potential (e.g., dissolution of carbonate minerals) in the tailings; and/or 2) enhanced sulfide mineral oxidation. With regards to the latter, pond water elevations in 2015 were 0.5 to 1 m lower than those in 2012-2013. Lower water elevations in the

tailings area would result in a greater degree of tailings de-saturation, which in turn could promote higher rates of sulfide mineral oxidation. In this regard, water management in the Tailings Pond may serve as an effective measure to minimize the extent of tailings de-saturation and acid generating processes; however, any geotechnical risks associated with such activity would need to be assessed and managed accordingly.

Inspection of redox-related parameters shows evidence for increasing Mn values in most wells since 2013, including MW09-1, MW09-2, MW09-3, MW09-21, MW09-22 and MW09-23 (Figure 11). Of these wells, MW09-2, MW09-21 and MW09-22 also show increases in dissolved Fe concentration in recent years. These observations may indicate a trend towards more reducing conditions in tailings porewaters, as supported by data for the Seepage Pond (discussed below).

Tailings Seepage Pond

Water quality data for the Tailings Seepage Pond represent a robust indicator of the overall environmental performance of the facility, as the waters that accumulate in this pond reflect the net contribution remobilization and attenuation processes that occur within the Tailings Pond, tailings porewater, and in underlying substrates.

Time series profiles of major ions for the Tailings Seepage Pond show trends of increasing concentration for TDS, SO₄ and Ca from 2011 to maxima in 2014, with values decreasing over the last half of 2014 and 2015 (Figure 12). These trends are not mirrored in the Tailings Pond, which typically shows trends of decreasing concentration for most salinity proxies (Figure 6). These observations suggest the trends in TDS, SO₄ and Ca in the Seepage Pond reflect processes within the tailings mass. This is supported by increasing values for SO₄ and Ca in some monitoring wells since 2010, including MW09-1, MW09-21 and MW09-22. As outlined above, increasing values for SO₄ and Ca may indicate the early stages of enhanced sulfide mineral oxidation.

Alkalinity and pH in the Seepage Pond show variable, though stable conditions (Figure 12). Sodium shows a progressive decline in concentration in the Seepage Pond since 2010 (Figure 12). Sodium is positively correlated with SCN, suggesting the Na decrease reflects the progressive flushing of residual cyanide mill reagents (added as NaCN). This trend is consistent with generally decreasing Na values in the Tailings Pond (Figure 6).

Inspection of redox-related parameters for the Seepage Pond shows evidence of changing redox conditions within the tailings facility. Specifically, dissolved Fe shows a pronounced increase in concentration from <5 mg/L (2010) to a maximum of 20 mg/L in early 2015 (Figure 13). Dissolved Mn also shows evidence of modest increasing concentrations, with maximum values observed in late 2014 and early 2015. Given the neutral pH conditions of seepage waters, such increases are interpreted to represent the enhanced reductive dissolution of Mn(IV)- and Fe(III)-oxide phases within the tailings mass.

The onset to more vigorous Mn(IV) and Fe(III) reduction may result from decreased availability of NO₃-N, which has shown a pronounced decrease in concentration since 2011 (maximum of 5.5 mg/L) to 2015 values ≤ 1 mg/L (Figure 13). In reduction-oxidation (redox) reactions in tailings porewaters, NO₃ will serve as a preferential electron acceptor over Mn(IV) and Fe(III) as dictated by thermodynamics. Specifically, redox conditions in saturated tailings are governed by a series of microbially-mediated redox reactions in which reduced carbon compounds (e.g., dissolved organic carbon - DOC) serve as electron donors to various oxidants that serve as terminal electron acceptors. The reaction sequence proceeds in an order which is determined by the net free energy yield, with aerobic oxidation (oxygen reduction) being the most favourable. In the absence of oxygen, nitrate presents the next most favourable reaction. Following nitrate reduction (denitrification), the redox sequence proceeds via Mn(IV)-oxide reduction, Fe(III)-oxyhydroxide reduction, sulfate reduction, and methanogenesis (CO₂ reduction) (Froelich et al., 1979).

Within the context of the tailings facility, the Seepage Pond data potentially illustrate a transition in redox conditions towards less denitrification and greater reduction of Mn(IV)- and Fe(III)oxides. Specifically, the data suggest the tailings system has entered a stage of nitrate limitation, whereby other redox reactions are now favoured. This conclusion is supported by groundwater data, which show increasing trends for dissolved Mn and Fe in several wells. The absence of a notable increase in Mn concentration in the Seepage Pond as compared to Fe may relate to the higher Mn values in the Tailings Pond (up to ~10 mg/L) (i.e., the higher Tailings Pond values may overwhelm the signature associated with reductive dissolution reactions within the tailings mass).

The transition towards more suboxic conditions within the tailings area is further supported by the data for dissolved As (Figure 14) which show an increase very similar to that of Fe. Indeed, the two parameters are strongly correlated ($r^2 = 0.73$). Arsenic shows a strong affinity to Fe oxides, and the congruent nature of their concentration profiles strongly suggest that As is being remobilized via the reductive dissolution of As-bearing Fe-oxyhydroxides.

Dissolved Zn concentrations show a pronounced increase in Seepage Pond waters in 2015 and 2016, from pre-2015 values of <0.02 mg/L to maxima of 0.09 mg/L (February 2015) and 0.12 mg/L (February 2016) (Figure 14). In both 2015 and 2016, the Zn peaks occur in the winter low-flow period when inputs to the Seepage Pond will be minimally diluted with surface runoff. This implies the Zn increases can be attributed to processes occurring within the tailings facility, and input to the pond via seepage pathways. The Zn increase in 2015 does not correlate with Fe and As, nor with concentration trends in the Tailings Pond, suggesting other process contribute to the observed increases. Evidence for enhanced sulfide mineral oxidation (as shown by data for SO₄, Ca and alkalinity in groundwater), and elevated Zn values in groundwater well MW09-1, may imply the Seepage Pond increases are linked to sulfide oxidation and acid generating reactions within the tailings mass.

Dissolved Cd also shows a peak in concentration in 2015, on the same day as observed for Zn (February 16, 2015), suggesting the behaviour of both elements are governed by similar controls. From a remobilization perspective, both Zn and Cd are predicted to be hosted in common sulfide phases in the tailings (e.g., co-occurrence in sphalerite), and therefore sulfide mineral oxidation processes would affect both elements. From an attenuation perspective, both Cd and Zn will be predicted to also share similar behaviours (e.g., removal as secondary sulfide phases).

Other possible explanations to account for the dramatic increases in Zn concentration in 2015 and 2016 may include (as outlined in SLR, 2015a): 1) non-steady-state feature condition associated with the breakthrough of a water parcel with elevated Zn (as supported by elevated Zn values in some wells); 2) reduction in Zn attenuation processes within tailings porewaters and/or underlying organic substrate; and 3) changes in flow patterns, permafrost distribution, and attenuation processes associated with warming temperatures. In SLR (2015a), no specific anomalies in the site snow/ice and hydrology data were identified that could account for the increase in Zn concentrations in the Seepage Pond.

In terms of other trace elements, dissolved Cu, Ni and Cr show progressively decreasing concentrations since 2010. The sharp transition in Cr values is interpreted to reflect a change in analytical protocols, given that the decrease observed on April 17, 2013 overlaps with similar jumps in concentration for Ni and Se.

2.3 Lower Dome Creek

Water quality trends for the Tailings Seepage Pond were compared to data for Lower Dome Creek (DC-U and DC-R) to assess the magnitude of downstream water quality impacts:

- DC-U: Lower Dome Creek, approximately 250 m downstream of the Seepage Pond and immediately downstream of the Dome Creek diversion channel;
- DC-R: Lower Dome Creek at road, approximately 1,500 m downstream of Seepage Pond;

As outlined in Section 2.2, several parameters show recent increases in concentration in the Seepage Pond (SO₄, Fe, Mn, Zn, Cd), while NO₃-N concentrations have been decreasing. The increase in SO₄ concentration observed between 2012 and 2014 is evident in lower Dome Creek at both DC-U and DC-R (Figure 15). With respect to redox-sensitive parameters, the dissolved Mn peak in the Seepage Pond in 2014 is congruent with peak values at DC-U (Figure 16). However, evidence for increasing trends in Mn concentrations over time is not apparent further downstream at DC-R. Comparison of Mn data between DC-U and DC-R suggest a slight effect of dilution downstream similar to SO₄. In contrast, the relative effect of dilution on Fe is markedly different as Fe concentrations show seasonal increase between DC-U and DC-R. Further, the progressive rise in dissolved Fe concentrations in the Seepage Pond since 2010 is not evident at

DC-U nor DC-R (Figure 16), suggesting that Fe is not behaving conservatively downstream of the Seepage Pond.

The data for dissolved Mn and Fe suggest both elements are being attenuated in lower Dome Creek via the precipitation of Fe-Mn oxyhydroxides. The dissolved Fe data specifically imply that a large proportion of the Fe attenuation occurs upstream of DC-U, while for Mn, the spatial scales of attenuation extend further downstream. It is possible these contrasts in behaviour relate to differences in reaction kinetics. Specifically, the kinetics of Fe oxidation/precipitation are very rapid (Davison, 1993), and would therefore expect Fe attenuation processes to occur within close proximity to the Seepage Pond. In contrast, the oxidation/precipitation kinetics for Mn can be slow, which could explain why Mn behaves relatively conservatively (e.g., similar to SO₄) in comparison to Fe.

With respect to trace elements, the elevated values observed for As, Cd, and Zn in the Seepage Pond in recent years are not clearly manifested in lower Dome Creek (Figure 17), suggesting commensurate attenuation of these elements with Mn and Fe. Comparison of downstream trends at DC-U and DC-R is somewhat hindered by the less frequent sampling collection at these sites. This is particularly evident for location DC-R, which has been sampled less frequently in the winter due to glaciation. The progressive decrease in NO₃-N values since 2011 is evident in lower Dome Creek at both DC-U and DC-R (Figure 16).

Assuming attenuation products are accumulating in lower Dome Creek, the potential for their remobilization must be considered. The precipitation of secondary Fe/Mn-oxide phases within and downstream of the Seepage Pond presents a leading candidate to explain the attenuation of As, Cd and Zn in lower Dome Creek. The potential for the remobilization of these elements will therefore relate to the potential for the remobilization of the secondary Fe-oxide phases, which in turn requires suboxic conditions. The potential for suboxia may be affected by both spatial and temporal factors. On a spatial scale, the progressive burial of Fe oxides phases may promote the development of suboxia below the sediment-water interface. In a temporal context, suboxic conditions are more likely to develop during the winter period, when ice-cover may restrict water-atmospheric interaction.

2.4 Victoria Creek

Water quality data for Victoria Creek (2010-2015) were examined for the following locations to assess the magnitude of mine-related water quality impacts:

- VC-UMN: Victoria Creek downstream of Dome Creek, and upstream of Minnesota Creek;
- VC-R: Victoria Creek at road, downstream of Dome Creek and downstream of Minnesota Creek;

- VC-U: Victoria Creek control, 20 m upstream of Back Creek confluence. This location is predicted to be influenced by Back Creek only during very high freshet flows (e.g., April and May of 2015); and
- VC-DBC: Victoria Creek downstream of Back Creek confluence, but upstream of Dome Creek.

Time series profiles for VC-UMN and VC-R show a high level of congruency, illustrating the minimal influence of Minnesota Creek on water quality in Victoria Creek (Figure 18). Downstream of the Dome Creek confluence, mine-related signatures are evident in Victoria Creek with respect to SO₄, Fe, Mn, As, Cd and Zn (Figure 18), as illustrated by the data for VC-UMN and VC-R in comparison to upstream values (VC-U).

In terms of temporal trends, increases in SO₄ since 2010 have been evident at both VC-UMN and VC-R (Figure 18). At VC-R, the mean annual SO₄ concentration increased from 22 mg/L in 2010 to 39 mg/L in 2015. Inspection of the SO₄ data for Victoria Creek upstream of the Dome Creek confluence (VC-U and VC-DBC) also shows evidence of increasing values (Figure 19). However, the magnitude of SO₄ values at VC-U and VC-DBC is not sufficient to account for the increases downstream of Dome Creek, suggesting that the recent increases in SO₄ concentration at VC-UMN and VC-R can be linked to the higher values observed since 2010 in the Seepage Pond and Lower Dome Creek (i.e., tailings-related source).

For other parameters of interest (e.g., As, Cd, Fe, Mn and Zn), the water quality data for Victoria Creek downstream of Dome Creek (VC-UMN and VC-R) do not reveal any temporal trends, with the possible exception of dissolved Cd, which shows evidence of decreasing values since 2010 (Figure 18). This perceived decrease cannot be attributed to changes upstream, since data for both VC-U and VC-DBC show higher Cd values in recent years (Figure 19).

3.0 Conclusions and Recommendations

3.1 Conclusions

- Time series data for DC-DX+105 illustrate pronounced mine-related signatures with respect to major ions (SO₄, Ca and alkalinity) and several trace elements (Mn, As, Cd and Zn). Contaminant levels cannot be linked to values in mill-area groundwater wells, illustrating the likely importance of adit-related seepage inputs to the surface water system (e.g., Huestis Adit).
- In terms of temporal trends, values for SO₄, Ca and alkalinity at DC-DX+105 have remained relatively constant since 2012. In contrast, the time series profiles for As, Cd and Zn show evidence of decreasing values.

- Data for major ions (e.g., SO₄ and Ca) in Upper Dome Creek show generally higher values downstream at DC-D1b in comparison to DC-D1 and DC-DX+105, likely relating to seepage inputs from historic mine wastes deposited downgradient of the mill area.
- With respect to redox-related parameters in Upper Dome Creek, dissolved Fe and Mn show the highest values at DC-B. Given the circum-neutral pH conditions, the elevated levels of Fe and Mn are predicted to reflect the input of suboxic waters to the creek system.
- The data for dissolved Cd and Zn in upper Dome Creek show strong parallels, illustrating that similar processes govern their remobilization and attenuation. For both parameters, the highest values are observed upstream at DC-DX+105, with progressively lower values occurring with distance downstream to minima at DC-B. Such trends may be explained in part by dilution but are contradicted by increasing trends in SO₄ downstream. The evidence therefore suggests considerable attenuation of Cd and Zn within the creek system.
- The Cd and Zn concentrations measured at DC-B are lower than values measured in the Tailings Pond and Tailings Seepage Pond as well as downstream at DC-U and DC-R, indicating that Upper Dome Creek (DC-B) contributes negligibly to the Cd and Zn signatures in Lower Dome Creek (DC-U and DC-R).
- Tailings Pond waters have shown a progressive decline in salinity proxies (e.g., SO4, Ca, TDS), several trace elements (Co, Cu and Ni) and NO₃-N since 2010. In contrast, As, Cd, and Zn do not show any definitive inter-annual trends in recent years.
- In tailings facility groundwater, SO₄ shows evidence of increasing concentrations in some wells since 2010, and in some cases, accompanied by commensurate increases in dissolved Ca and decreases in total alkalinity. These data may indicate the early stages of enhanced sulfide oxidation within the tailings mass. (*i.e.*, pyrite oxidation and associated release of sulfate, acidity and associated trace elements).
- Inspection of redox-related parameters shows evidence for increasing Mn and Fe values in several tailings wells since 2010. These observations may indicate a trend towards more reducing conditions in tailings porewaters, and is supported by observations from the Seepage Pond which include observations of denitrification and subsequent increasing trends in Fe (and to a lesser degree Mn) concentrations.
- The Tailings Seepage Pond shows a trend of increasing concentration for TDS, SO₄ and Ca from 2011 to maxima in 2014. These trends are not mirrored in the Tailings Pond, suggesting the trends reflect *in situ* processes within the tailings mass (possibly linked to enhanced sulfide mineral oxidation).
- Inspection of redox-related parameters for the Seepage Pond shows evidence of changing redox conditions within the tailings facility, as illustrated by a pronounced increase in the

concentration of dissolved Fe since 2010. Dissolved Mn also shows evidence of increasing concentrations in late 2014 and early 2015. These observations are indicative of a shift in redox pathways from NO₃ reduction to Fe/Mn-oxide reduction, in response to decreased NO₃-N values in seepage waters since 2011. This conclusion is supported by groundwater data which show increasing trends for dissolved Mn and Fe in several wells.

- The transition towards more reducing conditions within the tailings area is further supported by the Seepage Pond data for dissolved As, which shows a similar pattern of increase to that of Fe.
- Dissolved Zn and Cd also show a pronounced increase in Seepage Pond waters in 2015-2016. The Zn and Cd peaks, however, do not correlate with Fe and As, nor with concentration trends in the Tailings Pond, suggesting other process contribute to the observed increases in the Seepage Pond (possibly via enhanced sulfide mineral oxidation and/or early onset of localized acid mine drainage, as illustrated by data for SO₄, Ca and alkalinity in groundwater).
- The SO₄ increase observed for the Seepage Pond between 2012 and 2014 is evident in lower Dome Creek at both DC-U and DC-R. With respect to redox-sensitive parameters, the dissolved Mn peak in the Seepage Pond in 2014 is congruent with peak values at DC-U, although not evident further downstream at DC-R. The rise in dissolved Fe concentrations in the Seepage Pond since 2010 is not manifested at any of the downstream stations, which can likely be attributed to the attenuation of dissolved Fe in close proximity to the tailings facility.
- With respect to trace elements, the elevated values observed for As, Cd, and Zn in the Seepage Pond in recent years are not clearly manifested at downstream stations, illustrating their likely co-attenuation with Mn/Fe-oxides.
- Downstream of the Dome Creek confluence, mine-related signatures are evident in Victoria Creek with respect to SO₄, Fe, Mn, As, Cd and Zn. Increases in SO₄ concentrations since 2010 cannot be linked to upstream inputs to Victoria Creek. Rather, such increases are consistent with the higher values observed over the same time period in the Seepage Pond and Lower Dome Creek, suggesting a tailings-related source.
- No discernible inter-annual trends are evident for other parameters (e.g., As, Fe, Mn, Zn, NO₃-N, etc.) in Victoria Creek since 2010, with the possible exception of dissolved Cd, which shows evidence of decreasing values.

Closure

We trust that this memorandum meets your expectations at this time. Please contact the undersigned with any questions or comments.

Respectfully submitted, Lorax Environmental Services Ltd.

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Figure 3: Time series profiles for major ions and pH for surface water stations in Upper Dome Creek (2009-2015 data).





Figure 4: Time series profiles for redox-related parameters for surface water stations in Upper Dome Creek (2009-2015 data).



Figure 5: Time series profiles for dissolved As, Cd and Zn for surface water stations in Upper Dome Creek (2009-2015 data). Note log scales on Y axes for Cd and Zn.



Figure 6: Time series profiles for major ions, TDS and pH for the Tailings Pond.



Figure 7: Time series profiles for redox-related parameters for the Tailings Pond.





Figure 8: Time series profiles for trace elements for the Tailings Pond.





Figure 9: Time series profiles for major ions and pH for Tailings Management Area groundwater wells.



Figure 10: Time series profiles of dissolved As, Cd and Zn for Tailings Management Area groundwater wells. Note break in scale for Cd on Y-axis.



Figure 11: Time series profiles of redox-related parameters for Tailings Management Area groundwater wells.





Figure 12: Time series profiles for major ions and pH for the Seepage Pond (2010-February 2016 data).



Figure 13: Time series profiles for redox-related parameters for the Seepage Pond (2010-February 2016 data).



Figure 14: Time series profiles for trace elements for the Seepage Pond (2010-February 2016 data).





Figure 15: Time series profiles for SO4, alkalinity and pH for Seepage Pond and Lower Dome Creek (2010-2015 data).



Figure 16: Time series profiles for redox-related parameters for Seepage Pond and Lower Dome Creek (2010-2015 data).







Figure 17: Time series profiles for dissolved As, Cd and Zn for Seepage Pond and Lower Dome Creek (2010-2015 data).



Figure 18: Time series profiles for dissolved sulfate, nitrate-N, alkalinity and various trace elements (As, Cd, Fe, Mn and Zn) for Victoria Creek downstream of Dome Creek confluence, both upstream (VC-UMN) and downstream (VC-R) of Minnesota Creek. Data compared to control site VC-U.

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Figure 19: Time series profiles for dissolved sulfate, nitrate-N, alkalinity and various trace elements (As, Cd, Fe, Mn and Zn) for Victoria Creek upstream of Dome Creek confluence, both upstream (VC-U) and downstream (VC-DBC) of **Back Creek.**
1.1 Introduction

The Yukon Government (YG) has provided Lorax Environmental Services Ltd. (Lorax) access to a Sharepoint folder set-up for contractors. From this Sharepoint folder, historical laboratory reports and analytical databases from various contractors were made available to Lorax for the purpose of this assessment.

These historical laboratory reports and existing databases of surfacewater quality (SWQ) and groundwater quality (GWQ) for stations of interest in this assessment, have been compiled by Lorax into master databases of SWQ and GWQ which are available in electronic format upon request. It should be noted that QA/QC could not be conducted on all historical sources of data.

The sources and date ranges of SWQ and GWQ data from the various contractors are outlined below:

<u>SWQ:</u>

- AEH: May 2008 to March 2015
- EDI: April 2015 to October 2015
- ALS lab reports for EDI: Nov, Dec, 2015

GWQ:

- Lorax: June, July 2010, September 2011
- AMEC: September 2013, July 2014
- Hemmera: June, October 2014 and March, June, August, September 2015

Two checklists have been constructed showing SWQ and GWQ stations of interest for this assessment sampled by date and are presented as Tables 1 and 2 respectively. SWQ station locations are shown on Figure 1 and GWQ stations are shown on Figure 2.

Year		2010													
Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
DC-1			х												
DC-2															
DC-3															
DC-4															
DC-7															
WQ-DC-8															
WQ-DC-10															
WQ-DC-11															
WQ-DC-12															
WQ-DC-13															
WQ-DC-14															
WQ-DC-15															
WQ-DC-B															
WQ-DC-D1B															
WQ-DC-DX					Х	Х	Х	Х	Х						
WQ-DC-DX+105															
WQ-DC-R					Х	Х	Х	Х	Х	Х					
WQ-DC-U					Х	Х	Х	Х	Х	Х	Х	Х			
DC-D1					Х	Х	Х	Х	х	Х					
DC-U1															
DC-U2															
WQ-MS-S-03															
WQ-MS-S-08															
WQ-MS-S-A															
WQ-SEEP	х	Х	Х	Х	Х	Х	Х	Х	х	Х	Х	Х			
WQ-TP					Х	Х	Х	Х	х	Х	Х	Х			
WQ-VC-DBC															
WQ-VC-R					Х	Х	х	Х	х	х	Х	Х			
WQ-VC-R+150															
VC-REF					X	Х	X	Х	Х	X	Х				
WQ-VC-U	Х	Х	Х	Х	X	Х	X	Х	Х	X	Х	Х			
WQ-VC-UMN															

Table 1:Mt. Nansen SWQ stations sampled by date

Year	2011												
Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
DC-1													
DC-2													
DC-3													
DC-4													
DC-7													
WQ-DC-8													
WQ-DC-10													
WQ-DC-11													
WQ-DC-12													
WQ-DC-13													
WQ-DC-14													
WQ-DC-15													
WQ-DC-B													
WQ-DC-D1B													
WQ-DC-DX					х	Х	Х	Х	Х				
WQ-DC-DX+105													
WQ-DC-R					Х	Х	X	Х	Х	Х			
WQ-DC-U					Х	Х	X	Х	Х	Х	Х	Х	
DC-D1					Х	Х	X	Х	Х	Х		Х	
DC-U1													
DC-U2													
WQ-MS-S-03													
WQ-MS-S-08													
WQ-MS-S-A													
WQ-SEEP	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-TP	Х				Х	Х	Х	Х	Х	Х		Х	
WQ-VC-DBC													
WQ-VC-R					Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-R+150													
VC-REF					Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-U	Х	Х	Х	Х	X	Х	X	Х	Х	Х	Х	Х	
WQ-VC-UMN													

Year	2012												
Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
DC-1													
DC-2													
DC-3													
DC-4													
DC-7													
WQ-DC-8													
WQ-DC-10													
WQ-DC-11													
WQ-DC-12													
WQ-DC-13													
WQ-DC-14													
WQ-DC-15													
WQ-DC-B													
WQ-DC-D1B					Х		Х	Х	Х	Х			
WQ-DC-DX					Х	Х	Х	Х	Х	Х			
WQ-DC-DX+105				Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-DC-R				Х	Х	Х	Х	Х	Х	Х			
WQ-DC-U	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
DC-D1	Х			Х	Х	Х	Х	Х	Х	Х			
DC-U1					Х	Х	Х	Х	Х	Х	Х		
DC-U2					Х	Х	Х	Х	Х	Х			
WQ-MS-S-03				Х		Х	Х	Х	Х	Х	Х	Х	
WQ-MS-S-08											Х		
WQ-MS-S-A													
WQ-SEEP	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-TP	Х	Х	Х		Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-DBC				Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-R	Х		Х	Х	X	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-R+150												Х	
VC-REF	Х	Х			X	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-U	Х	Х	Х	Х	X	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-UMN				Х	х	Х	Х	Х	Х	Х	Х	Х	

Year	2013												
Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
DC-1													
DC-2													
DC-3													
DC-4													
DC-7													
WQ-DC-8													
WQ-DC-10													
WQ-DC-11													
WQ-DC-12													
WQ-DC-13													
WQ-DC-14													
WQ-DC-15													
WQ-DC-B													
WQ-DC-D1B					Х	Х	Х	Х	Х	Х	Х		
WQ-DC-DX					Х	Х	Х	Х	Х	Х	Х		
WQ-DC-DX+105	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-DC-R					Х	Х	Х	Х	Х	Х	Х		
WQ-DC-U	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
DC-D1					Х								
DC-U1					Х	Х	Х	Х	Х	Х	Х		
DC-U2					Х	Х	Х	Х	Х	Х	Х		
WQ-MS-S-03				Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-MS-S-08								Х					
WQ-MS-S-A													
WQ-SEEP	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-TP	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-DBC	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-R					X	Х	X	Х	Х	Х	Х		
WQ-VC-R+150	X	Х	Х	Х	X							Х	
VC-REF	Х	Х	X	Х	X	Х	X	Х	Х	Х	Х	Х	
WQ-VC-U	Х	Х	Х	Х	X	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-UMN	X	X	Х	Х	Х	X	Х	Х	X	Х	Х	X	

Year	2014												
Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
DC-1													
DC-2													
DC-3													
DC-4													
DC-7													
WQ-DC-8													
WQ-DC-10													
WQ-DC-11													
WQ-DC-12													
WQ-DC-13													
WQ-DC-14													
WQ-DC-15													
WQ-DC-B		Х		Х	х	Х	х	Х	Х	Х			
WQ-DC-D1B					х	Х	х	Х	Х	Х			
WQ-DC-DX					Х	Х		Х	Х	Х			
WQ-DC-DX+105	Х	Х			Х	Х	Х	Х	Х	Х	Х	Х	
WQ-DC-R					х	Х	х	Х	Х	Х			
WQ-DC-U	Х	Х	Х	Х	х	Х	х	Х	Х	Х	Х	Х	
DC-D1													
DC-U1													
DC-U2													
WQ-MS-S-03	Х		Х		х								
WQ-MS-S-08					х								
WQ-MS-S-A													
WQ-SEEP	Х	Х	Х	Х	х	Х	х	Х	Х	Х	Х	Х	
WQ-TP	Х	Х	Х	Х	х	Х	х	Х	Х	Х	Х	Х	
WQ-VC-DBC	Х	Х	Х	Х	х	Х	х	Х	Х	Х	Х	Х	
WQ-VC-R					х	Х	х	Х	Х	Х	Х		
WQ-VC-R+150	X	Х	Х	Х	x							X	
VC-REF	X												
WQ-VC-U	X	Х	Х	Х	X	Х	X	Х	X	X	Х	X	
WQ-VC-UMN	Х	Х	Х	Х	Х	Х	X	Х	Х	Х	Х	Х	

Year	2015												
Station/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
DC-1													
DC-2			Х										
DC-3			Х										
DC-4			Х										
DC-7			Х										
WQ-DC-8			Х					Х	Х	Х			
WQ-DC-10			Х					Х	Х	Х			
WQ-DC-11								Х	Х	Х			
WQ-DC-12								Х					
WQ-DC-13								Х					
WQ-DC-14								Х	Х				
WQ-DC-15									Х	Х			
WQ-DC-B				Х	Х	Х	Х	Х	Х	Х	Х		
WQ-DC-D1B					Х	Х	Х	Х	Х	Х			
WQ-DC-DX					Х	Х	Х	Х	Х	Х			
WQ-DC-DX+105	Х	Х			Х	Х		Х	Х	Х	Х	Х	
WQ-DC-R					Х	Х	Х	Х	Х	Х	Х		
WQ-DC-U	Х				Х	Х	Х	Х	Х	Х	Х	Х	
DC-D1													
DC-U1													
DC-U2													
WQ-MS-S-03			Х	Х	Х	Х	Х	Х	Х	Х			
WQ-MS-S-08					Х								
WQ-MS-S-A					Х				Х	Х			
WQ-SEEP	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-TP	Х	Х	Х		Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-DBC	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	
WQ-VC-R						Х	Х	Х	Х	Х	Х		
WQ-VC-R+150	X	Х	Х	Х	x							Х	
VC-REF													
WQ-VC-U	X	Х	Х	X	x	Х	х	Х	Х	X	Х	х	
WQ-VC-UMN	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	

Year	201	10	2011	2013	2014		2015				
Station/Month	Jun	Jul	Sep	Sep	Jun	Jul	Oct	Mar	Jun	Aug	Sep
GSI-DC-01B				Х			Х			Х	
GSI-DC-02B				Х			Х	Х		Х	Х
GSI-DC-03B				х			х			Х	
GSI-DC-05B				Х							
GSI-DC-06B				Х	Х		Х				х
GSI-DC-07B				Х	Х		Х				х
GSI-DC-08B							Х				
GSI-DC-09B				х	Х		Х				х
GSI-DC-10B				х	Х		Х				х
GSI-DC-5B											Х
GSI-HA-01A				Х			Х	Х	Х	Х	Х
GSI-HA-02A				Х			Х			Х	
GSI-HA-03A				х			х			х	х
GSI-HA-04A				х			х	Х		х	
GSI-HA-05A				х			х			х	
MP09-03											х
MP09-04		х	Х	х	Х		Х				х
MP09-05		х	х	х	х		х		х		х
MP09-08											х
MP09-09		х	х	х	х		х		х		х
MP09-10		х	х	х	х		х				х
MP09-11		х	х	х	х		Х		х		х
MP09-12		х	х	х	х		Х				х
MP09-14									Х		х
MW09-01		х	х	х					х		х
MW09-02		х	х	х	х	х	Х	Х	х		х
MW09-03	Х	Х	Х	х	Х	Х	Х		Х		Х
MW09-04	Х	Х	Х	Х	Х	Х	Х		Х		X
MW09-05		Х					Х				
MW09-06		Х					Х	Х	Х		Х
MW09-07			Х	Х	Х	Х	Х				
MW09-08		Х	Х	Х	х		Х		Х		X
MW09-11		х									
MW09-16		х	х	Х	х		Х		Х	Х	
MW09-17		Х	Х	Х	Х		Х		Х	Х	
MW09-18		х	Х	х	Х		Х	Х	Х	Х	
MW09-19		х	Х	х	Х		Х	Х	Х	Х	
MW09-21		х	х	х	х		Х				х
MW09-22			Х	х	Х		Х		Х		Х
MW09-23		х	X	х	Х		Х	Х	х		х
MW09-24		х	х	х	Х		Х	Х	х		х
W14103083BH02				X			Х				x
W14103083BH03				Х			Х		х		х
W14103083BH04							Х				Х

Table 2:Mt. Nansen GWQ stations sampled by date





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