MEMORANDUM

February 15, 2020

TO:	Nicole Pesonen, Nyrstar Myra Falls
FROM:	Telsa Willsey
RE:	IEG 2019 site inspection
COPY:	Justin Straker, IEG

On Sept. 25 2019, Telsa Willsey and Justin Straker of IEG conducted a site inspection of the Nyrstar Myra Falls mine related to reclamation areas and activities. The assessment and recommendations cover five primary areas/topics:

1. metals uptake in Sitka alder seeded in the Emergency Tailings Area;
2. assessment of revegetation in the Core Rack Area Borrow (CRAB);
3. assessment of revegetation in the Waste Rock Dump 2 area;
4. assessment of revegetation and metals uptake in red alder in the TDF Seismic Berm area; and
5. inspection of soil development, revegetation, and metals uptake in vegetation in the Waste Rock Dump 1 cover trial.

We discuss each of these inspection topics in detail below.

1. Emergency Tailings Area

The former Emergency Tailings Area is located east of the new camp area, and was seeded with Sitka alder in 2006 areas part of site reclamation efforts. The alder seed was encapsulated and broadcast by hand, resulting in a densely vegetated stand (Figure 1).

Foliar tissue samples were collected to assess metals uptake in vegetation growing at the Emergency Tailings Area. Four composite foliar samples were collected, each from current annual growth of at least three different individuals. Three samples of alder were collected, and because a low proportion of willow was also observed at the site, a single composite sample of willow was also collected. Samples were placed in sealed bags and chilled prior to delivery to the Ministry of Environment for analysis of 26 elements.

Element concentrations in foliar tissue were largely below the maximum tolerable thresholds set for ruminants (National Research Council, 2005); results for all 26 elements can be found in Appendix A. Concentrations of copper, molybdenum, lead, and zinc[1] are found in Table 1. Copper and lead levels in both Sitka alder and willow foliage were well below the maximum tolerance levels set for cattle[2] (National Research Council, 2005), and were also far below concentrations found in vegetation growing in industrial sites contaminated with these metals (Kabata-Pendias, 2010). Molybdenum was below the detection limit in both species. Zinc levels were below maximum tolerable levels for ruminants in all Sitka alder samples, but were elevated above the threshold in willow. Zinc concentrations in both species were comparable to excessive levels of zinc found in plants grown in sites contaminated by mining and farming (Kabata-Pendias, 2010).

Figure 1. Sitka alder growing in the Emergency Tailings Area (photo Sept. 2019).

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[1] Because copper, lead, and zinc concentrations are primary commodities produced by Myra Falls Operations, there is greater potential for uptake of these metals by vegetation growing in the area. Molybdendum concentrations are monitored due to the potential of molybdenosis, a secondary copper deficiency in ruminants associated with high dietary Mo concentrations (>100 ppm), or when dietary Copper to Mo (Cu:Mo) ratios are below 2:1 (National Research Council [2005]).

[2] Data for cattle are used because cattle are ruminants, with digestive systems similar to those of wild ungulates (e.g., black-tail deer) that are resident in the Myra Creek valley and observed on reclaimed areas of the mine. Published data on the dietary tolerances of wild ungulates is not available.

Table 1. Concentrations of copper, lead, molybdenum, and zinc (mg/kg) in foliar tissue from Sitka alder and willow growing in the Emergency Tailings Area. Values in bold exceed maximum tolerance levels for cattle outlined by the National Research Council (2005).

Species	Copper (Cu)	Lead (Pb)	Molybdenum (Mo)	Zinc (Zn)
1-Sitka Alder	23	1.5	< DL[3]	380
2-Sitka Alder	16	2.2	< DL	320
3-Sitka Alder	22	1.8	< DL	380
4-Willow	27	2.7	< DL	**850**
Maximum tolerance level for cattle in mg/kg diet (National Research Council, 2005)				
	40	10	5	500

2. Core Rack Borrow Area

The Core Rack Borrow Area (CRAB) was hydroseeded in 2016 with a mix shown in Table 2. Surveys conducted in 2017 and 2018 found some species from the seed mix were growing in the area, particularly Oregon-grape, fireweed, pearly everlasting, and sedges, and natural ingress of species such as willow, fescue and alder from surrounding undisturbed areas was evident. However, germination from the hydroseeding was observed to be poor, and most of the area was unvegetated (Figure 2).

Despite the presence of the above listed species, this area remained primarily unvegetated when revisited in September 2019. The presence of Himalayan blackberry was also noted, suggesting that control for invasive species is warranted.

As noted in the Reclamation Inspection report for 2018, signs of significant, active erosion at the CRAB were not evident, but the area should be frequently monitored for signs of active erosion. Hydroseeding at the site has had limited success and is not likely to perform better without a new, more aggressive seed mix. A seed mix comprised of aggressive native grasses would likely create more cover than the 2016 hydroseed mix, but could risk altering vegetation successional pathways, preventing establishment of shrubs and trees. Planting red alder is likely to provide the best results, though some areas are steep, and will require safety precautions to be taken during planting. One option may be to plant the areas which are not steep slopes after hydroseeding the steep slopes with an aggressive seed mix, or leaving them to revegetate naturally (Figure 2). The roads should be decommissioned and de-compacted prior to planting. Himalayan

[3] DL = detection limit.

blackberry is also present at this site, so any revegetation efforts at this site will need to include control for this species.

Table 2. 2016 hydroseed blend.

Species			%	Seeds/g	Grams purchased	# Individual seeds
Shrubs	Dull Oregon-grape	*Mahonia nervosa*	0.13%	65	500	32,500
	Red huckleberry	*Vaccinium parvifolium*	2.22%	5,400	105	567,000
	Salal	*Gaultheria shallon*	20.90%	7,100	751	5,332,100
	Sitka mountain ash	*Sorbus sitchensis*	0.02%	308	20	6,160
	Snowberry	*Symphoricarpos albus*	0.01%	178	20	3,560
Herbs	Pearly everlasting	*Anaphalis margaratacea*	49.74%	17,621	720	12,687,120
	Fireweed	*Chamerion angustifolium*	7.84%	20,000	100	2,000,000
	Goatsbeard	*Aruncus dioicus*	17.29%	9,524	463	4,409,612
	Upland sedges	*Carex* spp.	1.67%	1,500	284	426,000
	Vanilla leaf	*Achlys triphylla*	0.17%	112	388	43,456

Figure 2. Core Rack Borrow Area. Options for reclamation in this area include hydroseeding oversteepened areas with an aggressive native seed mix, followed by planting the headscarp and old road areas with red alder or leaving these areas for natural revegetation (LFN) (photo Sept. 2019).

3. Waste Rock Dump 2 Area

Myra Falls removed waste rock from the historic Waste Dump 2 location in the summer and early fall of 2017. Underlying materials at this location consist of native surficial materials—including soil and other surficial material—onto which the waste rock was dumped (Figure 3). Analysis in 2017 indicated that these materials have the edaphic properties of the 03/HwCw – Salal site series in the CWHmm1 biogeoclimatic unit. Appropriate tree species for early revegetation are Douglas-fir and red alder, and seedlings of both species were observed in non-mined forest directly above the Waste Dump 2 location.

In 2018, surveys of the Waste Rock Dump 2 area found sparse vegetation establishing across the area, making up approximately 5% of the ground cover. The most common species are fireweed, miner's lettuce, thimbleberry, and pearly everlasting. Other notable native species present include Douglas-fir, red alder, and red elderberry. Similar observations were made in when the area was re-visited in 2019, including the establishment of invasive and non-native species (Himalayan blackberry and thistle).

Figure 3. Area currently stripped and ready for revegetation in the previous Waste Dump 2 location (photo taken in 2018).

Figure 4. Vegetation establishing at Waste Rock Dump 2 (photo taken in 2019).

Appropriate treatment for this area includes planting of red alder and Douglas-fir, at approximate stem densities of 2500 and 1000 stems per ha respectively. Discussions with AMEC engineers in 2017 indicate that they do not expect erosion to be a primary issue at this site; therefore at this time no additional treatments such as seeding or bioengineering are recommended. Revegetation efforts should be coupled with the removal of invasive species from the area and planning for future control.

Analysis of element concentrations in this material was performed in 2018, which indicated high concentrations (approximately 1-6 times the Canadian parkland/agricultural soil quality guidelines) of cadmium, copper, lead, and zinc, as well as more marginally elevated concentrations of arsenic, barium, and vanadium. Although it is possible that there is some contribution in these concentrations from naturally mineralized materials, it is also very likely that they reflect the effects of either constituent leaching from waste-rock materials or incomplete removal of these materials. Observed concentrations are unlikely to be limiting to reestablishment of vegetation, but vegetation in this area should be sampled for element uptake in the future.

4. TDF Seismic Berm

Visual surveys of the berm were conducted in 2018 and 2019 to assess overall vegetation development, particularly the comparative performance of the areas planted in 2010 vs the areas planted in 2008, as well as to note the presence of invasive species in these areas. These were reconnaissance surveys, whereas full assessments of the permanent sample plots established in 2012 are expected to take place in 2020.

Consistent with observations made in 2018, the alder planted in 2008 on the eastern portion of the seismic berm was found to be growing well in 2019, with a continuous litter layer making up most of the ground cover (Figure 5). Substantial growth of Canada bluegrass (*Poa compressa*) was observed in the vicinity of plot 2-4, and several sedges (*Carex* sp.) were growing near plot 2-5 (in the south-eastern portion of the berm) (Figure 6). The canopy in this section appears to be, for the most part, preventing establishment of weedy species, though one occurrence of bull thistle was noted in 2018.

The more recently planted (2010) western section is not performing as well. The aspect is more southerly, and thus likely more prone to drought, and trees are smaller and produce less litter than those of the eastern section did at the same age. It is possible that this area only requires more time to initiate nutrient cycling and will continue to grow at a stable pace, but there are likely some low-cost interventions which could improve performance and may prevent possible mortality of planted trees. We recommend hydroseeding a mix of native understory species, along with fertilizer, mulch, and tackifier. Hydroseeding should be completed in the early spring to coincide with nutrient uptake, ideally before new leaves come out. The hydroseeding should occur from the top of the berm, down the slope, use minimum application pressure, and should focus on areas of bare soil, and avoid areas with higher tree cover. If hydroseeding of these areas is not possible, the areas would benefit from application of a slow release fertilizer, applied using a manual cyclone spreader.

Figure 5. Seismic Berm ground cover (photo taken in 2018).

Figure 6. Establishment of sedge and Canada bluegrass in the south-eastern portion of the TDF Seismic Berm (photos Sept. 2019).

Three composite foliar samples of red alder were collected in 2019 for element analysis, each from at least three different individuals. Samples were sealed in plastic bags and chilled prior to delivery to the Ministry of Environment, as described in section 1. Levels of copper, lead, molybdenum and zinc are shown in Table 3, and the full analysis for all elements is found in Appendix A. Samples were collected at the west end (sample 1), middle (sample 2), and east end (sample 3) of the berm.

Copper and lead concentrations were well below maximum tolerable levels for cattle (National Research Council, 2005). The concentration of molybdenum in alder foliage was below the threshold in samples from the middle and eastern portions of the berm, but was elevated at the west end. The ratio of copper to molybdenum is slightly above 2:1, making it unlikely that molybdenosis is a concern for browsing ruminants in this area. However, we recommend continuing to monitor molybdenum concentrations on the berm. Similar to concentrations in Sitka alder growing in the Emergency Tailings Area, zinc levels were below tolerable levels for ruminants but were comparable to levels found in vegetation growing in contaminated industrial sites (Kabata-Pendias, 2010).

Table 3. Concentrations of copper, lead, molybdenum, and zinc (mg/kg) in foliar tissue from red alder growing in the TDF Seimic Berm Area. Values in bold exceed maximum tolerance levels for cattle outlined by the National Research Council (2005).

Sample ID and species	Copper (Cu)	Lead (Pb)	Molybdenum (Mo)	Zinc (Zn)
1-Red Alder	15	4.1	**7**	190
2- Red Alder	21	3.2	1.9	130
3- Red Alder	20	2.5	1.3	150
Maximum tolerance level for cattle in mg/kg diet (National Research Council, 2005)				
	40	10	5	500

5. Waste Rock Dump 1 Area

A field program was initiated in 1998 in the Waste Rock Dump 1 Area to assess the performance of three test covers placed over acid-generating waste rock. This area was visited in 2019 to determine if soil development was occurring, and to assess revegetation and metals concentrations in vegetation and lichen.

Soil development was assessed by digging a small pit approximately 40 cm deep and examining the pit walls for evidence of horizon formation. The top 30 cm was composed of oxidized brown till, below which was a subsoil layer of grey till. Abundant rooting was observed in the surficial brown till layer, with root diameters up to 5 mm. A fine-root sod mat was present at the soil surface, due to significant growth of creeping red fescue in the area. A 5-mm litter and 5-mm fermentation layer were observed, but there has been insufficient activity for any further development of soil horizons.

Soil samples were taken at 0-10, 10-20, 20-30 cm, and from the subsoil layer below 30 cm to measure nitrogen, carbon, organic material by loss on ignition (LOI), and pH (Table 4). Nutrient concentrations, organic matter, and pH are fairly consistent between each sample of the brown till layer; organic matter is highest in the top 10 cm and decreases slightly with increasing depth. The low nutrient and organic content in the grey subsoil layer, combined with a neutral pH, indicate that this layer is relatively unweathered. These results indicate no or at most very weak evidence of mineral-soil development in these materials, other than the accumulation of organic litter at the soil surface.

Table 4. Nitrogen, carbon, loss on ignition (LOI), and pH of soil sampled from the Waste Rock Dump 1 area.

Sample ID	%N	%C	%LOI	pH
0-10 cm	0.074	1.6	4.3	4.78
10-20 cm	0.07	1.5	4.2	5.12
20-30 cm	0.08	1.8	4.1	4.86
Subsoil	< DL[4]	0.18	0.77	7.64

Several native and non-native species are present at Waste Rock Dump 1 (Table 5) though vegetation in this area was relatively sparse overall. Foliage from Douglas-fir and a western white pine was collected for element analysis as described in sections 1 and 4, except the white-pine sample was collected from a single individual as no other trees of this species were in the area. All Douglas-fir appeared healthy, whereas the white pine was chlorotic. Copper, lead, molybdenum, and zinc were all below maximum tolerable levels for ruminants in both species (National Research Council, 2005), but zinc uptake was comparable to that observed in industrial contaminated sites (Kabata-Pendias, 2010) (Table 6).

Stereocaulon lichen was collected at both the Waste Rock Dump 1 Area (*Stereocaulon tomentosum*) and the site of the old camp (*S. grande*) to assess element concentrations. Elevated metal concentrations in lichen tissue could be useful in indicating if pollution is occurring via wind dispersal of contaminated dust. Copper, lead, molybdenum and zinc levels are all within the range of "background" concentrations observed in lichen species, and are well below elevated ranges observed in lichen species growing at or near sites contaminated by industrial activity (Nash, 1989)

[4] DL = Detection Limit

Table 5. Plant species at Waste Rock Dump 1.

Species Name	Common name	Native (N) or exotic (E) in BC
Pseudotsuga menziesii	Douglas-fir	N
Pinus monticola	Western white pine	N
Festuca rubra	Creeping red fescue	E
Agrostis capillaris	Colonial bentgrass	E
Symphoricarpos mollis	Trailing snowberry	N
Thuja plicata	Western red cedar	N
Ceratodon purpureus	Fire moss	N
Stereocaulon sp.	Foam sp.	N
Racomitrium elongatum	Long rock-moss	N
Polytrichum juniperinum	Juniper haircap moss	N
Lotus corniculatus	Birds-foot trefoil	E
Tsuga heterophylla	Western hemlock	N

Table 6. Concentrations of copper, lead, molybdenum, and zinc (mg/kg) in foliar tissue from Douglas fir (*Pseudotsugae menziesii*) and Western white pine (*Pinus monticola*) growing in the Waste Rock Dump 1 Area. Values in bold exceed maximum tolerance levels for cattle outlined by the National Research Council (2005).

Species	Copper (Cu)	Lead (Pb)	Molybdenum (Mo)	Zinc (Zn)
Western white pine	16	8	2.3	150
Douglas-fir	13	7.9	< DL[5]	120
Maximum tolerance level for cattle in mg/kg diet (National Research Council, 2005)				
	40	10	5	500

[5] DL = Detection limit

Table 7. Concentrations of copper, lead, molybdenum, and zinc (mg/kg) in foliar tissue from *Stereocaulon* sp. growing in the Waste Rock Dump 1 Area.

Species	Sample Area	Copper (Cu)	Lead (Pb)	Molybdenum (Mo)	Zinc (Zn)
Stereocaulon tomentosum	Waste Rock Dump 1	94	47	0.51	410
Stereocaulon grande	Old Camp	100	55	1.2	450

Closure

We thank Nyrstar for the opportunity to contribute to ongoing reclamation works at the Myra Falls mine, and trust the information provided in this memo meets your requirements at this time. To discuss content of this memo and/or work required going forward, please contact me at twillsey@iegconsulting.com, or at 778 679 4993.

References

Kabata-Pendias, A. (2003). *Trace elements in soils and plants* (4th ed.). Boca Raton, FL: CRC Press.

Nash, T.H. (1989). Metal tolerance in lichens. In *Heavy metal tolerance in plants: evolutionary aspects* (119-132). Boca Raton, Fl: CRC Press.

National Research Council (2005). *Mineral tolerance of animals* (2nd ed.). Washington, DC: National Academies Press.

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Appendix A – Laboratory Results

Analysis Report

Ministry of Environment and Climate Change Strategy
Environmental Sustainability and Strategic Policy Division
Knowledge Management Branch - Analytical Chemistry Research Laboratory

Requisition # T2082
Submitter Telsa Willsey
Office: IEG Consulting
Project NMFARI-19
Date In: 30-Sep-19
Date Out: 25-Oct-19

Revised Report
Report revised to include ICP-MS (extended, low-level) data. All other data is unchanged.
Data is reported on a dry weight basis unless otherwise noted.

Sample	Combustion, Flash 2000 Total Nitrogen %	Combustion, Flash 2000 Total Carbon %	Combustion, Flash 2000 Total Sulphur %	Acid Digestion, IC Sulphate (S) mg/kg	Ag mg/kg	Al mg/kg	As mg/kg	B mg/kg	Ba mg/kg	Be mg/kg	Ca mg/kg
Est DL	0.01	0.01	0.01	20	0.05	30	0.01	1	1	0.05	25
1				94	0.13	160	0.15	12	87	< DL	7800
2				190	< DL	310	0.17	11	58	< DL	7300
3				230	0.076	130	0.19	11	92	< DL	7600
4				1700	< DL	620	0.37	19	79	< DL	12000
5				670	< DL	190	0.29	11	47	< DL	19000
6				250	0.061	180	0.27	11	34	< DL	15000
7				380	0.058	110	0.19	13	24	< DL	15000
8	1.7	52	0.19	710	0.11	770	0.58	160	55	< DL	5100
9	1.1	53	0.11	300	0.15	780	15	210	140	< DL	3800
10				190	1.1	2100	5.7	4.6	130	< DL	1200
11				120	0.95	4500	7.6	3.1	560	0.057	1500

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Metals via Microwave Digestion, ICP-MS											
Cd	Co	Cr	Cu	Fe	Hg	K	Mg	Mn	Mo	Na	Ni
mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
0.02	0.01	2	1	5	0.03	20	5	0.1	0.5	30	0.1
0.29	0.44	< DL	23	150	< DL	5100	1400	370	< DL	< DL	3.5
0.53	0.48	< DL	16	240	< DL	3800	1200	270	< DL	36	4
0.32	0.32	< DL	22	160	< DL	6300	1100	290	< DL	< DL	3.6
2.9	1.8	2	27	1100	< DL	10000	1900	760	< DL	120	24
0.33	0.12	< DL	15	240	< DL	4100	1300	150	7	< DL	1.6
0.19	0.14	< DL	21	230	< DL	4400	1500	200	1.9	< DL	1.4
0.17	0.18	< DL	20	160	< DL	4000	1600	320	1.3	< DL	1.5
0.58	0.28	< DL	16	470	< DL	5900	1600	300	2.3	< DL	2.6
0.4	0.27	< DL	13	420	< DL	5800	990	290	< DL	< DL	2.4
1.7	0.86	2.5	94	3200	< DL	1700	820	51	0.51	200	5.1
1.9	1.8	4.6	100	7600	< DL	2200	1300	84	1.2	210	8

P mg/kg	Pb mg/kg	S mg/kg	Se mg/kg	Sr mg/kg	V mg/kg	Zn mg/kg	Sample ID
5	0.05	700	0.1	0.1	0.5	1	
2100	1.5	1400	< DL	20	< DL	380	ETA-1
1600	2.2	1200	< DL	19	< DL	320	ETA-2
1900	1.8	1400	< DL	18	< DL	380	ETA-3
2000	2.7	3200	< DL	34	1.3	850	ETA-4
1100	4.1	1700	< DL	27	0.5	190	Seismic Berm - 1
1800	3.2	1400	< DL	25	0.53	130	Seismic Berm - 2
1700	2.5	1500	< DL	24	< DL	150	Seismic Berm - 3
1800	8	1900	0.45	47	1.2	150	WRD-1 Pw
1900	7.9	1000	0.22	53	0.97	120	WRD-1 Fd
530	47	1400	0.29	6.3	6.9	410	Stereocaulon Old Camp
460	55	3400	0.52	13	14	450	Stereocaulon WRD1

Analysis Report

Ministry of Environment and Climate Change Strategy

Environmental Sustainability and Strategic Policy Division

Knowledge Management Branch - Analytical Chemistry Research Laboratory

Requisition #	S1952
Submitter	Telsa Willsey
Office:	IEG Consulting
Project	NMFARI-19
Date In:	30-Sep-19
Date Out:	28-Oct-19

Final Report

Data reported on a dry weight basis unless otherwise indicate

Sample	**Combustion N %**	**Combustion C %**	**Muffle Furnace LOI %**	**Manual Meter pH (1:1, soil:water)**	**Sample ID**
Est DL	**0.01**	**0.01**	**0.01**		
1	< DL	0.18	0.77	7.64	Subsoil
2	0.074	1.6	4.3	4.78	0-10cm
3	0.07	1.5	4.2	5.12	10-20cm
4	0.08	1.8	4.1	4.86	20-30cm