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KMP SO_2 EEM Program – Technical Memo S07

Long-term Soil Monitoring Plots

Laboratory Analysis

June 2018

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1 Overview

Under the Environmental Effects Monitoring (EEM) Program, long-term soil monitoring plots will address the observation-based KPI: 'observed change in base cation pool over time' through repeat sampling and analysis of soils for exchangeable base cations every five years (ESSA et al., 2014).

During October–December 2015, long-term soil monitoring plots (primary and secondary) were established at Coho Flats and at Lakelse Lake, Kitimat valley, and during June–July 2016 the reference (background or control) plots were established at Kemano. Technical memo S04 (2015) described the establishment of the plots (i.e., plot locations and design), and the initial sampling and processing of soils. Technical memo S06 (2016) described the establishment of the control plots at Kemano, and the sampling of soil bulk density sampling and mapping of trees across all plots during June–July 2016.

This memo (S07) describes the extraction and analysis of the mineral soil samples from the primary plots at Coho Flats and Lakelse Lake for exchangeable base cations and exchangeable acidity, which was carried out during 2017. There are 20 soils samples, collected from three depths, per plot; a total of 120 soil samples.

2 Objective and Rationale

The objective of the long-term soil plots is to monitor changes in soil base cation pools over time through repeated sampling and analysis (every five years). The monitoring plots provide a framework for replicate random sampling of soils, allowing for the statistical assessment of changes between sampling campaigns.

Plot establishment and initial soil sampling was carried out during 2015; the first resampling of soils from the primary plots at Coho Flats and Lakelse Lake is scheduled for June 2018.

3 Plot Location and Design

During October–December 2015, near-field and far-field plots were established at Coho Flats (latitude: 54.07660, longitude: –128.65117) and Lakelse Lake (latitude: 54.37827, longitude: –128.57990), respectively, and during 2016 the control plots were established at Kemano (latitude: 53.53032, longitude: –127.97384; see Appendix Figure A1 and Figure A2). At each location, primary and secondary (backup) plots were established within forest stands dominated by western Hemlock.

Each long-term soil plot is 32 m by 30 m in size and composed of twenty 8 m by 6 m sub-plots lettered A to T; the A sub-plot is oriented to the north-west corner of each plot (see Appendix Figure A3). Each sub-plot is further divided into twelve 2 m by 2 m sampling grids (numbered 1 to 12); one numbered grid was randomly sampled from each lettered sub-plot at five depths (see Appendix Table A1 for a list of sample grids): litter-fibric (LF), humic (H), and 0–5 cm, 5–15 cm, and

15–30 cm depths in the mineral soil (yielding a total of 100 soil samples for each plot, i.e., 5 soil samples by depth within each of the 20 lettered sub-plots).

4 Laboratory Analysis

All soil samples (collected during 2015 and 2016) from the 0–5 cm, 5–15 cm, and 15–30 cm depths have been dried, sieved to < 2 mm and analysed for pH, organic matter content and bulk density. Soils from the primary plots at Coho Flats and Lakelse Lake have been analysed for exchangeable base cations and exchangeable acidity.

Soil bulk density core samples were weighed, oven dried at 105°C for 24 hours, and reweighed. The difference between the wet and oven dry weights provided an estimate of field soil moisture content. The dried soil was sieved to < 2 mm (fine fraction), the volume of the coarse material (>2 mm) was measured by displacement. Bulk density was estimated using the dry weight of the fine fraction (<2 mm) and the volume of the core (adjusted for coarse fragment volume).

Composite mineral soil samples were air dried and sieved (<2 mm). The fine fraction was analysed for organic matter content by loss on ignition (LOI); 5 g of soil was placed into a muffle furnace at 400°C for 10 hours and then reweighed to determine percent loss. Soil pH was measured by mixing 5 g of soil with 20 mL of water and analysed using a pH probe.

Exchangeable acidity was measured using a potassium chloride (KCl) extraction; 5 g of soil was mixed with 25 mL of KCl, the solution was extracted via vacuum filtration. The sample then received five addition washes of 25 mL KCl. The extractant (135 mL) was titrated with sodium hydroxide (NaOH) to determine exchange acidity (H^+ + Al^{3+}). The extractant (15 mL) was also analyzed by ICP–OES to determine exchangeable aluminum (Al^{3+}).

Exchangeable base cations were measured using an ammonium acetate (NH_4OAC) extraction, 5 g of mineral soil was mixed with 25 mL of NH_4OAC, the solution was extracted via vacuum filtration. The sample then received two addition washes of 10 mL NH_4OAC, the extractant was analyzed by ICP–OES for exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Fe^{3+} and Mn^{2+}).

5 Soil Chemistry

Exchangeable base cations were estimated as the sum of calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+). Cation Exchange Capacity (CEC), was estimated as the sum of all cations and exchangeable acidity (which is the sum of exchangeable aluminium (Al^{3+}) and hydrogen (H^+)), this is technically termed effective CEC. Base saturation (%) was estimated as the percentage of effective CEC made up of base cations. Exchangeable base cations pools in the 0–30 cm soil was estimated by multiplying the concentrations of base cations by soil bulk density.

The multiple observations per depth allow the variation in soil properties to be assessed between and within plots. There is a noticeable difference in organic matter content between depths in the mineral soil at Lakelse Lake (i.e., there is a statistically significant decrease in organic matter between the 0–5 cm and the lower depths, Figure 1) but not between primary and secondary plots (i.e., there is no statistical difference between the 0–5 cm at Lakelse Lake primary compared with the same depth in Lakelse Lake secondary). In contrast, there is no significant difference (decrease) in organic matter with depth at the Coho Flats primary plot (see Figure 1 and **Error! Reference source not found.**)

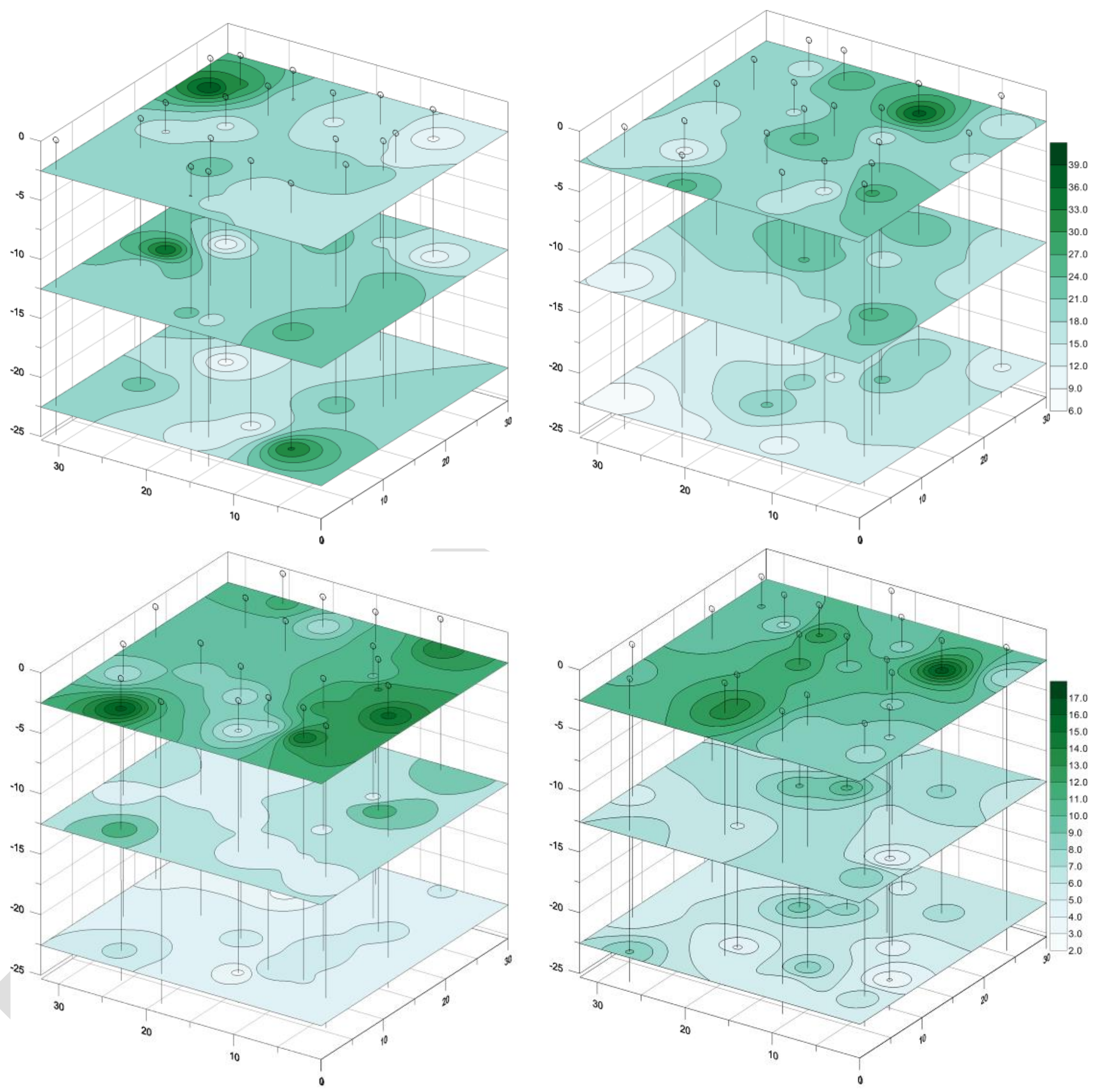

Figure 1. Three-dimensional representation of soil organic matter content (%) in the 0–5 cm, 5–15 cm, and 15–30 cm (mineral) soil depths at the primary (left) and secondary (right) long-term soil monitoring plots at Coho Flats (upper) and Lakelse Lake (lower). The vertical lines indicate the location of the soil sampling pits (n = 20 per plot, with soil sampling at three depths). Note: the difference in scales between plots.

In general, pH and bulk density in forest soils increase with depth and organic matter decreases; however, at Coho Flats both bulk density and organic matter do not show this pattern (Table 1). In contrast, exchangeable base cations, acidity and effective CEC decrease with depth at both plots (Table 1). Lakelse Lake has higher soil pH, bulk density and lower organic matter compared with Coho Flats (Table 1 and Table 2).

Average base saturation (%) at Lakelse Lake is 47%, which is notably higher compared with 17% at Coho Flats. The base saturation is higher throughout all soil depths at Lakelse Lake, especially the 0–5 cm and 5–15 cm soil depths (Figure 2). While total cations (effective CEC) is similar between plots (Table 1), the soils in Lakelse Lake are dominated by base cations (average 2.8 meq $100g^{-1}$) compared with Coho Flats (average 1.3 meq $100g^{-1}$). As a result, base cation pools are > 4 times larger at Lakelse Lake compared with Coho Flats (Table 2), 7217 meq m^{-2} compared with 1667 meq m^{-2}, respectively. It is important to note that the higher bulk density at Lakelse Lake also influences base cation pools (Table 2).

Table 1. Average soil chemistry data per depth (n = 20) for the primary long-term soil monitoring plots at Coho Flats, and Lakelse Lake.

Soil variable (meq $100g^{-1}$)	Coho Flats | Soil depth (cm) 0–5	5–15	15–30	Lakelse Lake | Soil depth (cm) 0–5	5–15	15–30
pH	4.56	5.07	5.33	5.13	5.41	5.50
Organic matter (%)	19.04	20.33	17.93	10.59	6.52	4.50
Bulk density (g cm^{-3})	0.433	0.416	0.509	0.537	0.856	0.982
Exchangeable Ca^{2+}	1.09	0.92	0.97	4.37	2.79	0.88
Exchangeable Mg^{2+}	0.32	0.30	0.24	1.67	1.37	0.26
Exchangeable K^{+}	0.13	0.13	0.10	0.13	0.05	0.11
Exchangeable Fe^{3+}	0.06	0.07	0.07	0.14	0.12	0.03
Exchangeable Mn^{2+}	0.01	0.02	0.01	0.20	0.12	0.03
Exchangeable acidity	7.84	6.77	5.82	3.68	2.86	2.24
Exchangeable base cations$^{\$}$	1.53	1.35	1.30	6.17	4.21	1.25
Cation Exchange Capacity$^{\$}$	9.44	8.20	7.20	10.18	7.31	3.55
Base saturation (%)	16.22	16.44	18.07	60.57	57.61	35.22

$^{\$}$ Exchangeable Base Cations was estimated as the sum of calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^{+}); Cation Exchange Capacity (CEC) was estimated as the sum of all cations and Exchangeable Acidity (which is the sum of exchangeable aluminium (Al^{3+}) and hydrogen (H^{+})), this is also known as effective CEC.

Table 2. Average soil chemistry and relative standard deviation (CV%) for the primary long-term soil monitoring plots at Coho Flats and Lakelse Lake (in the 0–30 cm depth).

Soil variable	Unit	Coho Flats (0–30 cm) Average	CV%	Lakelse Lake (0–30 cm) Average	CV%
Bulk density	g cm^{-3}	0.436	33.7	0.863	16.5
Organic matter	%	18.13	24.2	8.07	32.3
Exchangeable Ca^{2+}	meq $100g^{-1}$	0.91	74.3	1.90	49.9
Exchangeable Mg^{2+}	meq $100g^{-1}$	0.26	43.1	0.80	72.3
Exchangeable K^{+}	meq $100g^{-1}$	0.11	38.8	0.09	39.6
Exchangeable acidity	meq $100g^{-1}$	6.07	41.8	2.59	27.4
Exchangeable base cations	meq $100g^{-1}$	1.27		2.79	
Base cation pool	meq m^{-2}	1667		7217	

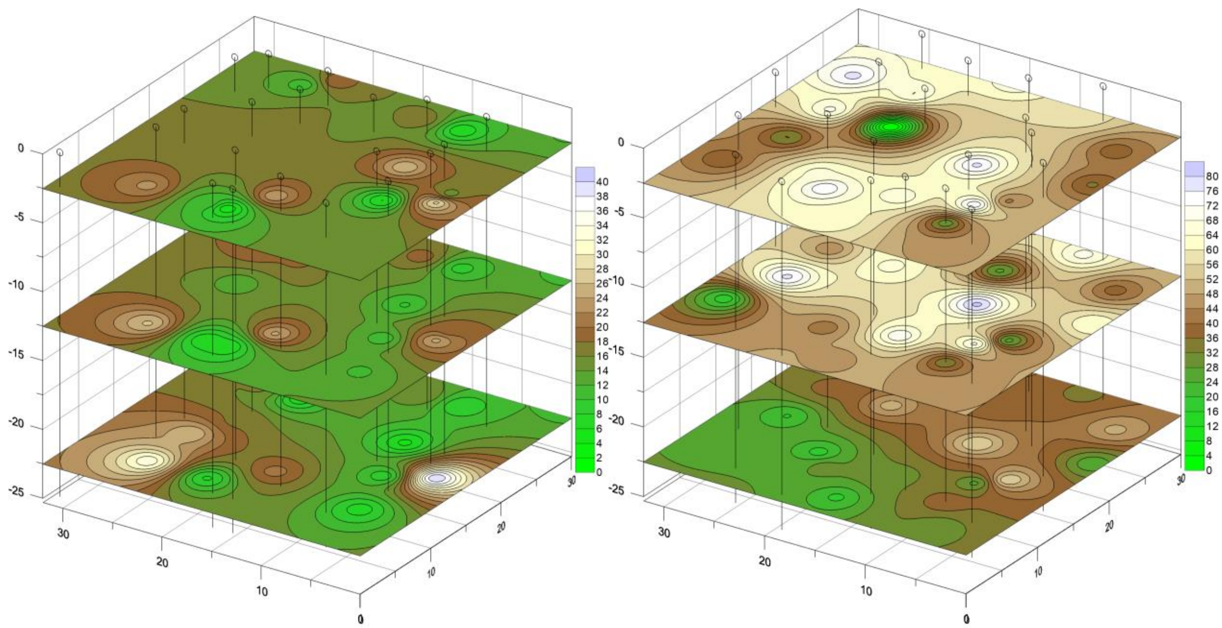

Figure 2. Three-dimensional representation of soil base saturation (%) in the 0–5 cm, 5–15 cm, and 15–30 cm (mineral) soil depths at the primary long-term soil monitoring plots at Coho Flats (left) and Lakelse Lake (right) The vertical lines indicate the location of the soil sampling pits (n = 20 per plot, with soil sampling at three depths). Note: the difference in scales between plots.

6 Literature Cited

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Vol.2: Final Technical Report. Prepared for RTA, Kitimat, BC. 450 pp.

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7 Appendix A

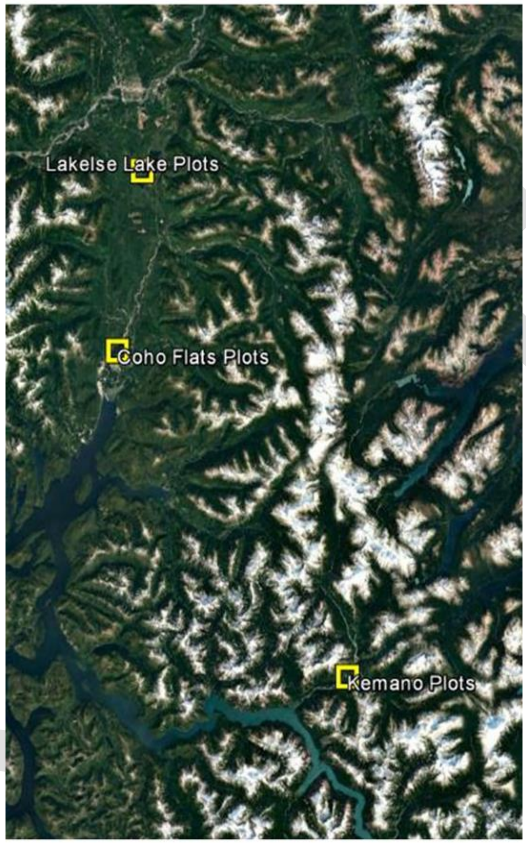

Figure A1. Location of long-term soil monitoring plots at Coho Flats (near-field) and Lakelse Lake (far-field), in the Kitimat Valley, and Kemano (reference). Note: primary and secondary [backup] plots were established at all three locations.

Figure A2. The long-term soil monitoring plots are located at Lakelse Lake beside the NADP monitoring station (A), in a western Hemlock stand (primary plot is shown in B), and east of the Coho Flats Trail, Kitimat (primary plot is shown in C). The reference (or background) plot is located in Kemano (primary plot at Seekwyakin camp is shown in D).

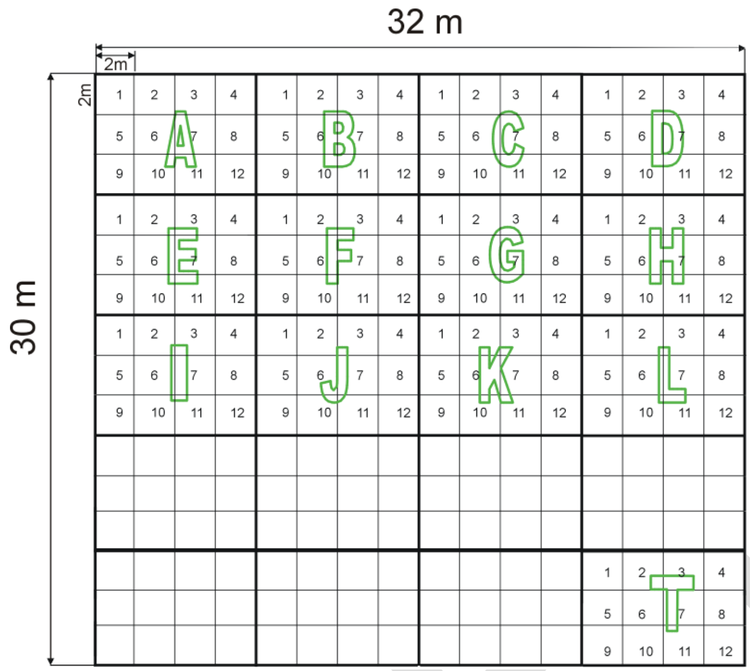

Figure A3. Long-term soil monitoring plot; the plot is divided into twenty 8 m by 6 m sub-plots, lettered A to T; each sub-plot is further divided into twelve 2 m by 2 m sampling grids, numbered 1 to 12. One numbered grid within each lettered sub-plot is randomly selected for sampling during each campaign, allowing for a total of 12 sampling events, with 20 samples per depth.

Table A1. Soil plot grids sampled (at five depths) during 2015 within the primary and secondary plots located at Coho Flats and Lakelse Lake (see Figure A1). Grids are identified by the sub-plot letter and grid number (see Figure). Grid locations for the primary plots are also shown in Figure A1.

#	Coho Flats		Lakelse Lake		Kemano	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
1	A12	A10	A10	A10	A09	A08
2	B08	B06	B11	B06	B02	B12
3	C05	C03	C02	C10	C10	C03
4	D04	D07	D05	D02	D09	D12
5	E11	E07	E04	E06	E03	E04
6	F03	F01	F02	F02	F04	F07
7	G06	G05	G09	G02	G12	G06
8	H06	H01	H07	H04	H03	H11
9	I11	I04	I06	I08	I12	I09
10	J05	J12	J01	J09	J06	J01
11	K12	K05	K04	K10	K09	K09
12	L02	L06	L12	L11	L08	L06
13	M03	M01	M04	M12	M08	M02
14	N12	N02	N05	N04	N09	N04
15	O07	O03	O06	O11	O04	O11
16	P11	P06	P09	P09	P03	P07
17	Q03	Q06	Q12	Q01	Q12	Q02
18	R02	R02	R07	R03	R07	R04
19	S03	S07	S06	S09	S06	S10
20	T02	T05	T09	T03	T09	T04