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KMP SO_2 EEM Program – Technical Memo S05

Steady-State Soil Modelling

Revised Modelling and Mapping of Terrestrial Critical Loads: 2017 Update

(Update to 2016 Technical Memo S03)

March 2017

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1 Overview

To support the Key Performance Indicator 'critical load exceedance risk' under the Environmental Effects Monitoring (EEM) Program, critical loads of acidity for (upland) forest soils will be revised during 2017.

Revised modelling and mapping of terrestrial critical loads will incorporate additional (new) observational data, improved regionalisation methods and updated model parameters as recommended under the STAR (ESSA et al., 2013) or following the Kitimat Airshed Emissions Effect Assessment (KAEEA; ESSA et al., 2014).

This memo (S05) updates the March 2016 'Steady-State Soil Modelling' memo (S03), by incorporating supplemental soil data (n = 15) collected during June–July 2016 (see Technical Memo S02: Steady-State Soil Modelling – Supplemental Soil Sampling, March 2015).

Note: The March 2015 'Steady-State Soil Modelling' memo update (S03), incorporated the weight-of-evidence approach for assessing whether a change in critical load exceedance (if predicted) is causally related to the Kitimat Modernisation Project (KMP).

2 Weight-of-Evidence Approach

Under the EEM Program, critical loads are used to evaluate the potential risk of both acidification and eutrophication to terrestrial ecosystems in the Kitimat Valley. A 'critical load' refers to the maximum amount of deposition (acidic or nutrient) that an ecosystem can tolerate without long-term harmful effects (i.e., ecosystem acidification or eutrophication). Critical loads for a specified ecosystem are widely estimated using mass balance models, which take into account sources and sinks of acidity or nutrients (see UNECE, 2004). The assessment of risk is based on the area and magnitude of critical load exceedance, i.e., where deposition is in excess of the critical load.

Under the EEM Program, exceedance of critical loads will be assessed under pre-KMP and post-KMP modelled deposition scenarios. The difference in deposition between the two scenarios represents deposition owing to KMP. As such, any change in critical load exceedance between the scenarios (if predicted) is causally related to KMP.

3 Critical Loads: 2017–2018 Updates

The mapping and modelling of critical loads during 2017–2018 under the EEM Program will follow the methodology described in the STAR (ESSA et al., 2013) incorporating seven principal revisions (labelled A to G).

A. Soil data. Under the STAR, 51 soil plots were sampled and analysed for bulk density, organic matter content, particle size distribution and total element content. These data were used to estimate soil base cation weather rates, which were subsequently regionalised across the study domain.

Since 2013, additional soil sampling has been carried out in the STAR study domain (see Appendix A Figure A1) under several external projects (KAEEA [n = 8], BC Ministry of Forest Experimental

Plots [EP0712; n = 3], Trent University [n = 1] and the LNG Canada Project [URL: lngcanada.ca; n = 22]). Further, as recommended in the STAR, supplemental soil sampling was carried out during July 2016 (n = 15; red filled-circles in Figure 1; see Appendix B Table B1 for exact location of the supplemental soil pits) to address critical uncertainties and data gaps (ESSA et al., 2013; Technical Memo S02). Soil data for the determination and mapping of soil base cation weathering rates (a key determinant of critical loads) is available from 100 sites within the Kitimat Valley (Figure 1), composed of soil samples physically collected from 78 sites during 2012–2017, following a consistent sampling and analysis protocol as described under the STAR (ESSA et al., 2013), and data for 22 sites obtained from LNG Canada.

All supplemental soils (three depths per site) were analysed for pH, loss-on-ignition (LOI: estimated of soil organic matter) and particle size (sand, silt and clay). Field soil moisture content (during sampling) and bulk density were determined on the fixed-volume core samples from the centre pit for each site. A weighted-average mineral soil sample for each site (i.e., composite of all depths weighted by bulk density) was analysed for total oxide content (n = 15), and composite samples from several sites were analysed for qualitative mineralogy (n = 6). Prior to analysis all mineral soil samples were air dried and sieved to 2 mm, the weight and volume of the >2 mm coarse fragments were recorded for the fixed-volume core samples, and samples for oxide and qualitative mineralogy were further pulverized to ~ 100 µm. Total oxide analysis was carried out by the Analytical Sciences Laboratory, Western University, Ontario on a PANalytical PW-2400 X-ray Flourescence Spectrometer (see Figure 2). Qualitative mineralogy analysis was carried out by the Department of Earth, Oceans and Atmospheric Sciences, University of British Columbia by X-ray Diffraction on a Siemens (Bruker) D5000 Bragg-Brentano diffractometer.

Soil base cation weathering rates will be estimated at each location with soil major oxide content (Figure 1) using the Analysis to Mineralogy (A2M) solver (Posch and Kurz 2007) and the PROFILE model (Warfvinge and Sverdrup 1992).

Task A. All new soil data will be captured and incorporated into the STAR soils database. Base cation weathering rates will be estimated for all additional soil sampling plots with total element content data following the methodology used in the STAR.

B. Soil mapping. Under the STAR, the regionalisation of soil weathering rates was carried out by allocating the statistical summaries from 4–6 sampling plots to mapped bedrock classes across the region. The approach did not accommodate the variability in weathering rates within each class and provided limited or no integration of surficial geology.

The KAEEA used a regression-kriging approach (Hengl et al. 2004), which is a well-established geostatistical mapping technique (McBrantley et al., 2003) for regionalisation of soil parameters, e.g., weathering rates. The approach provided a better representation of the spatial variability in weathering rates, removing the dependency on bedrock classes.

Task B. Spatial prediction or regionalisation of soil input parameters for the determination of critical loads, e.g., weathering rates and soil organic matter will be carried out using regression-kriging. The approach will incorporate all available soil data in the study area (see revision A).

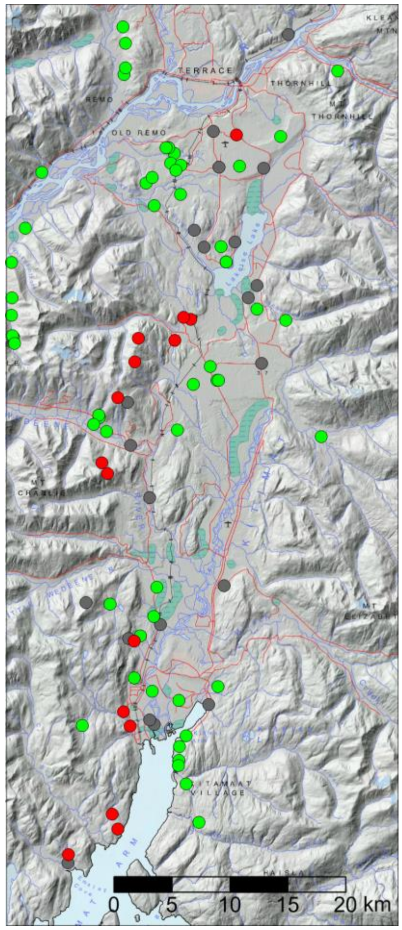

Figure 1. Location of soil sampling sites (n = 100) with observations of total element data for determination of soil base cation weathering rates within the Kitimat Valley; soil samples were collected from 78 sites (green and red filled-circles) during the period data 2012–2017 (red filled circles n = 15, were collected during summer 2016), in addition soil data for another 22 sites (grey filled-circles) were obtained from LNG Canada.

C. Base cation deposition. Under the STAR, the determination of critical load did not include base cation deposition. This was recognised as a critical uncertainty.

The National Atmospheric Deposition Program (NADP) precipitation chemistry stations at Haul Road and at Lakelse Lake provide data to evaluate regional base cation deposition. In additional, data may be supplemented with observations from other precipitation stations in western North American, and regional maps of rainfall volume.

Task C. Base cation deposition will be mapped across the study domain and incorporated into the determination of critical loads of acidity for (upland) forest soils.

D. Background sulphur and nitrogen deposition. Under the STAR, modelled sulphur and nitrogen deposition estimates did not include background deposition estimates. The modelled deposition represented the contribution of stationary and mobile emissions sources to total deposition, rather than total anthropogenic deposition to the study domain. Transboundary atmospheric sources can contribute a significant amount of anthropogenic sulphur and nitrogen deposition, as observed by monitoring stations in background regions.

The KAEEA (ESSA et al., 2014) incorporated a constant sulphur deposition of 10 meq m^{-2} yr^{-1} and nitrogen deposition of 5 meq m^{-2} yr^{-1} to represent background deposition. The selected values represented precautionary estimates of background deposition as actual background deposition will vary across a region.

Task D. Incorporation of background sulphur and nitrogen deposition in the determination of exceedance of critical loads following the KAEEA (ESSA et al., 2014).

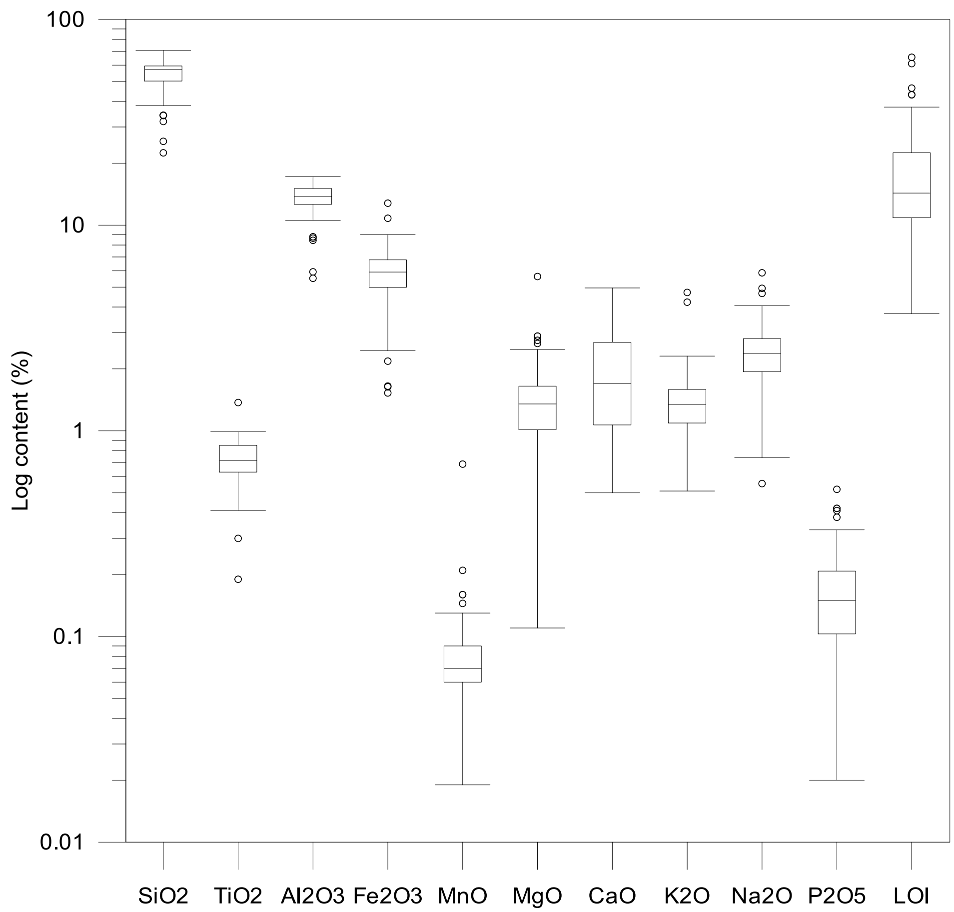

Figure 2. Box plot showing soil total element content (log %) and organic matter contnet (LOI) for sampling pits (n = 100) within the Kitimat Valley (see Figure 1 for pit location). Soil base cation weathering rates will be estimated at each location with soil total element content (following the protocol developed under the STAR).

E. Critical Bc:Al ratio. Under the STAR, a Bc:Al ratio equal to 1.0 was used as the critical chemical criterion or indicator of damage to receptor ecosystems, i.e., upland forest ecosystems on mineral soil. In contrast, the KAEEA (ESSA et al., 2014) incorporated broad vegetation-specific critical limits, i.e., Bc:Al = 1.0 for coniferous forests and Bc:Al = 6.0 for deciduous and mixed forests.

Following the approach used for the KAEEA, the EEM Program will incorporate vegetation-specific Bc:Al limits into the revised critical loads of acidity. In collaboration with the BC MOE, regionally-relevant vegetation-specific Bc:Al ratios will be identified from available literature sources (e.g., Sverdrup and Warfvinge, 1993). A map overlay or decision tree approach will be used to delineate or map identified vegetation types from existing spatial databases (see Technical Memo V01: Vegetation Resource Inventory Metadata, December 2014).

Task E. Spatial delineation of unique vegetation types within the study domain and assignment of vegetation-specific Bc:Al ratios. Incorporation of vegetation-specific Bc:Al ratios into the determination of critical loads of acidity.

F. Multiple chemical criteria. Under the STAR, the exceedance of critical loads for acidity (and subsequent risk rating) was based on one chemical criterion, i.e., Bc:Al = 1.0 for forest ecosystems. In contrast, the KAEEA incorporated a multi-criteria approach to evaluate the influence of the chosen criterion on predicted exceedance. Four critical chemical criteria were selected (ESSA et al., 2014).

Following the KAEEA, the EEM Program will incorporate a sensitivity analysis on the influence of the chosen criterion on predicted exceedance. In consultation with the BC MOE, a range of critical chemical criteria will be identified from literature sources (e.g., UNECE 2004).

Task F. Determination of exceedance of critical load under multiple chemical criteria to assess the influence of the chosen criterion on predicted exceedance following the KAEEA (ESSA et al., 2014).

G. Effects domain. The Key Performance Indicator ‘critical load exceedance risk’ is estimated as the proportional areal exceedance of the receptor study domain. In the absence of provincially-established air zone boundaries, the STAR used a study domain along the Kitimat valley encompassing the modelled post-KMP 10 kg SO_4^{2-} ha^{-1} yr^{-1} deposition plume and potentially sensitive terrestrial and aquatic receptor ecosystems. This study domain was defined in agreement with BC MOE, and encompassed 1991 km^2 of forested ecosystems on mineral soil (69% of the study area). The proportional exceedance reported in the STAR was referenced to this domain area. Under the KAEEA (ESSA et al. 2014), the BC MOE favoured an ‘effects domain’ based on the area under the modelled 7.5 kg SO_4^{2-} ha^{-1} yr^{-1} deposition plume.

The EEM Program will evaluate exceedance under both domains.

Task G. Determination of proportional areal exceedance using the original domain and an effects domain defined by the area under the 7.5 kg SO_4^{2-} ha^{-1} yr^{-1} deposition plume.

4 Literature Cited

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Appendix A. STAR, KAEEA, EP0712 and LNG soil sampling pits

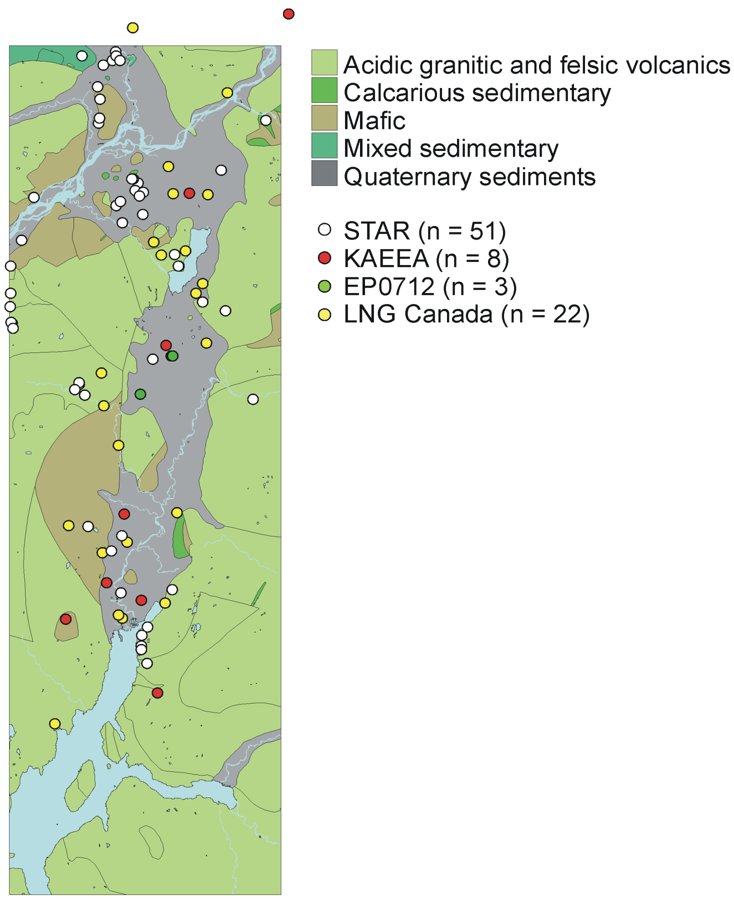

Figure A1. Location of soil sampling pits with total element analysis within (and outside) the STAR (ESSA et al., 2013) study domain. In addition to the 51 soil plots sampled under the STAR, soil plots have been sampled under the Kitimat Airshed Emissions Effect Assessment (KAEEA; n = 8), the BC Ministry of Forestry experimental growth plots (EP0712, n =3) and the LNG Canada Project (n = 22). The map depicts major bedrock and surficial (glaciofluvial material indicated as 'quaternary sediments') geology in the study area.

Appendix B. Location of supplemental soil sampling pits

Table B1: Location (latitude and longitude; decimal degrees) of supplemental soil sampling pits (n = 16). For location see red-filled circles in Figure 1.

#	ID	Latitude	Longitude	Notes
1	A01	54.21106	-128.73848	LNG Canada soil chemistry plot. Helicopter access
2	A02	54.27010	-128.72496	LNG Canada soil chemistry plot. Helicopter access
3	A03	54.29795	-128.70241	LNG Canada soil chemistry plot. Helicopter access
4	A04	54.31601	-128.69710	LNG Canada soil chemistry plot. Helicopter access
5	A05	54.21925	-128.74606	Helicopter access
6	E01	54.01448	-128.71008	On RTA property
7	E02	54.02568	-128.71893	On RTA property
8	L01	54.31455	-128.64862	EEM monitored lake L23.
9	L02	54.33215	-128.63716	EEM monitored lake L06.
10	L03	54.33066	-128.62736	EEM monitored lake L06.
11	L28	54.08047	-128.70444	Trail to L28; EEM monitored lake
12	P01	54.47381	-128.56547	Lodgepole pine plot requested by BC MOE
13	S01	53.91461	-128.79173	South-west of RTA property
14	S02	53.94606	-128.73470	South-west of RTA property
15	S03	53.93431	-128.72674	South-west of RTA property
16	SS01	54.02652	-128.70317	On RTA property[$]

[$] Sampled during July 2015