SUDBURY AREA RISK ASSESSMENT

VOLUME III: APPENDIX GD-9-2
SOIL CHARACTERIZATION LOE RANKING REPORT

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GD-9-2-1.0 INTRODUCTION

The evaluation of the physical and chemical soil quality parameters (excluding the concentrations of COC) outlined in this report forms one line of evidence (LOE) which contributes to an overall weight-of-evidence approach to address Objective #1 of the Ecological Risk Assessment (ERA). Objective #1 of the ERA aims to evaluate the extent to which COC may be preventing the recovery of regionally representative, self-sustaining terrestrial plant communities in the Sudbury region.

To fulfill this objective, multiple lines of evidence were collected and evaluated. Soil samples were collected at 22 sites (including 3 reference sites, 18 test sites and one historically limed and re-greened site) with differing soil metal concentrations in the Sudbury region during the 2004–2005 ERA Field Studies. The rationale and approach for site selection (Section 3.3 in Chapter 3 of Volume III), soil sample collection, analysis and results (Section 3.5 in Chapter 3 and Appendices GB and GD of Volume III) can be found under separate cover.

The objective of the soil characterization LOE was to measure the nutrient contents and mineral soil binding capacities at each site to determine whether the site soils could be considered a good growing medium. Each site was then ranked according to the soil physical and chemical parameters related to site productivity, irrespective of the concentration of the chemicals of concern (COC) presented at the site.

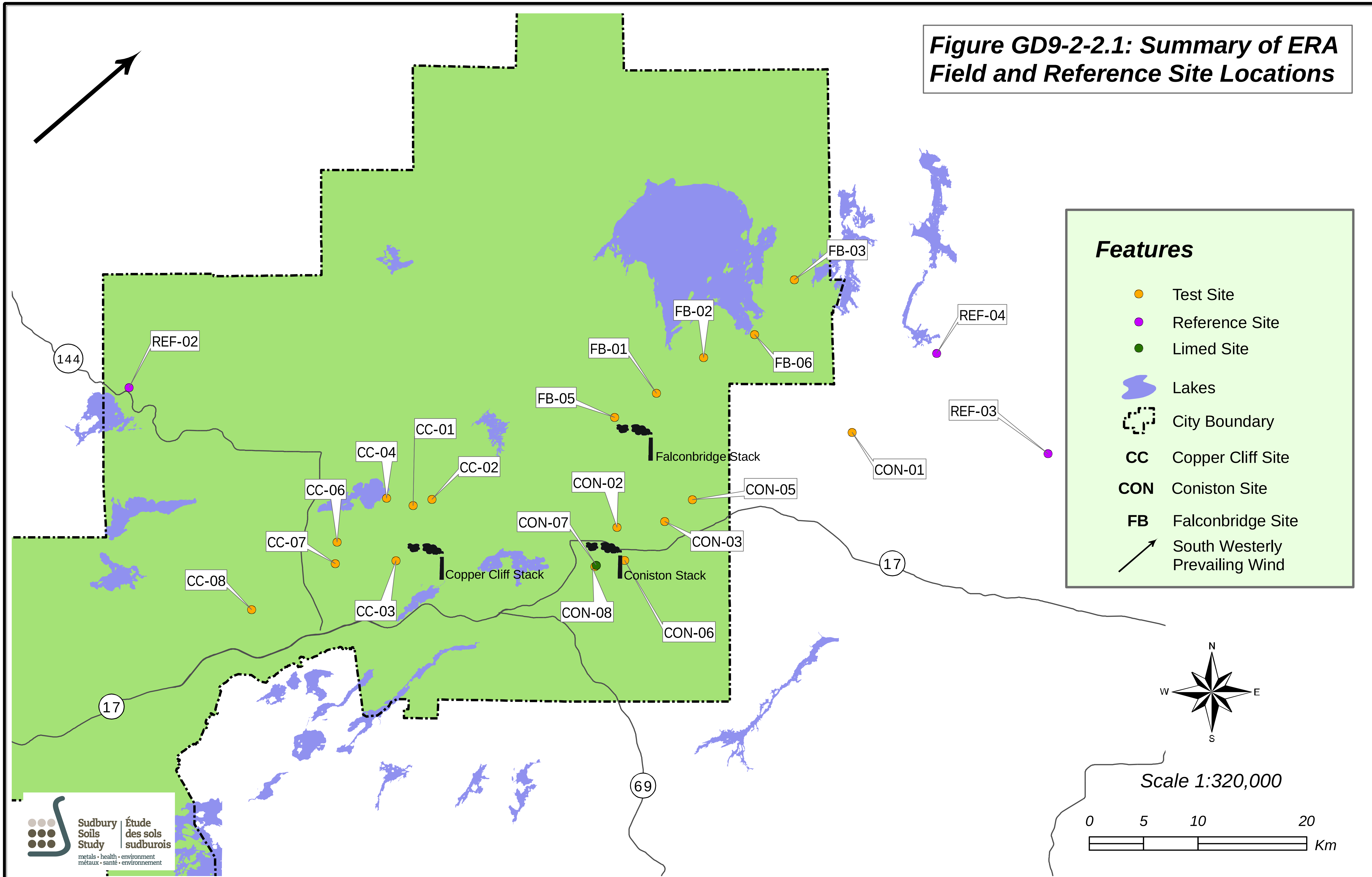
The objective of this report is to describe and present the approach taken to evaluate the soil quality and to provide a ranking for each test site.

GD-9-2-2.0 SITE LOCATIONS

A total of 22 sites were established: 18 test sites, 1 historically limed and re-greened site (CON-07) and 3 reference sites. All test sites radiated from current and historical smelter sources in Copper Cliff (seven test sites), Falconbridge (five test sites) and Coniston (six test sites and one historically limed site). The three reference sites displayed a variety of soil characteristics and plant communities, but contained only background metal concentrations. The locations of the test and reference sites are shown in Figure GD-9-2-2.1.

Two test sites on the Coniston transect are adjacent to each other. CON-07 has been historically limed and re-greened whereas CON-08 has received no treatment. Both sites are included in this ranking report but CON-07, the historically limed site, is not considered in the final site ranking. Instead a comparison of the soil quality at CON-07 and CON-08 is presented in Chapter 3, Section 3.14.2.

Figure GD9-2-2.1: Summary of ERA Field and Reference Site Locations



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GD-9-2-3.0 RANKING APPROACH

The approach used to rank the soil chemistry results (not including metal content) is summarized in Figure GD-9-2-3.1 and in the steps outlined in the following sections.

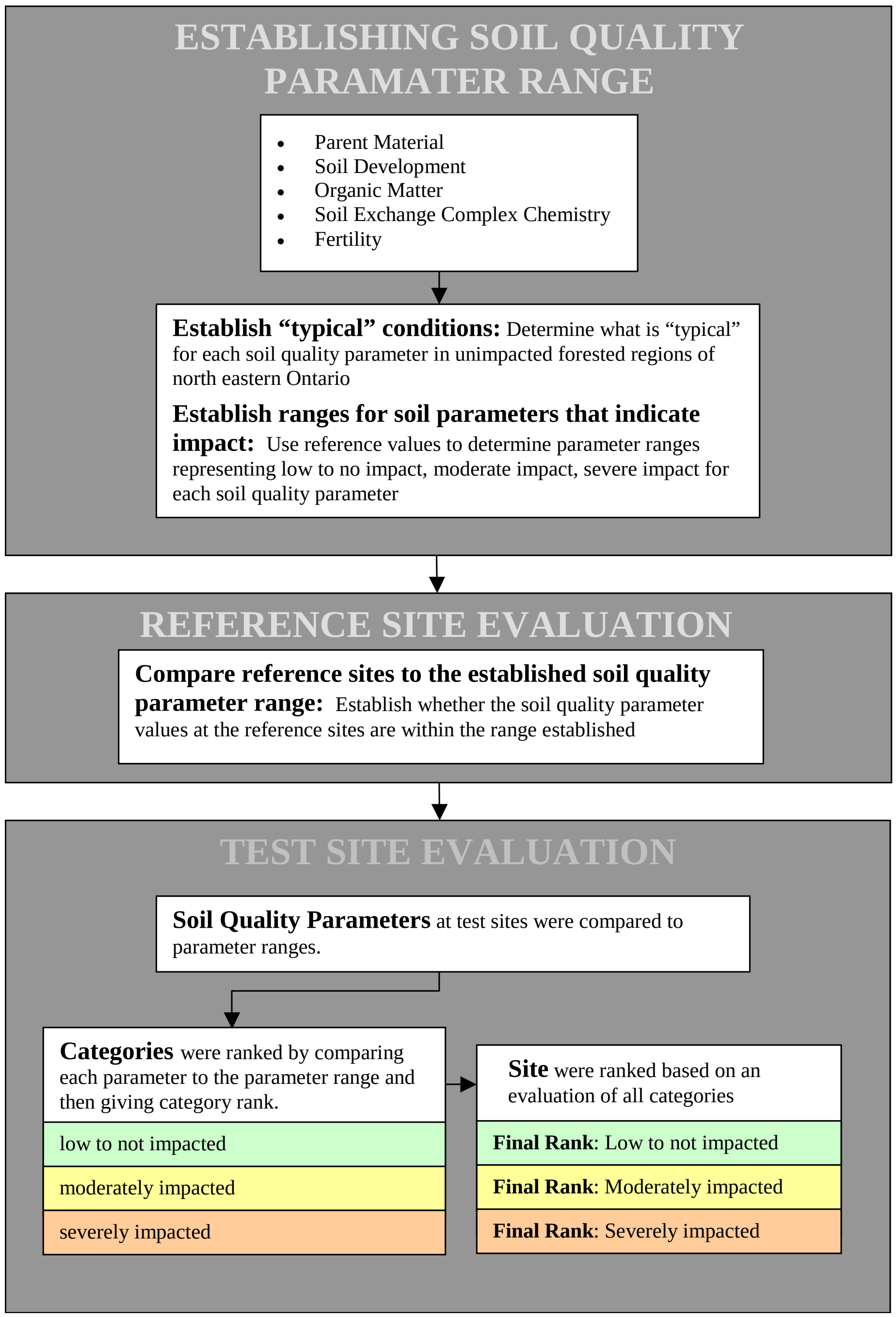

Figure GD-9-2-3.1 Final Ranking Scheme for Test and Reference Site Soils Based on Soil Chemistry Parameters

GD-9-2-3.1 Overview

At each site the following soil quality parameters were assessed:

- Parent material
- Soil Development
- Organic Matter
- Soil Exchange Complex Chemistry
- Fertility

The parameters are described in Section GD-9-2-3.2 below. The reference sites were characterized and evaluated to establish that the soils were roughly comparable to other soils in healthy, northeastern forests. In general, sites were ranked by comparing them to reference site values for each parameter, and by using professional judgment.

Reference Site Evaluation

The following steps were taken to evaluate the reference sites**:**

- For each soil quality parameter, it was determined which values could be considered "typical" for unimpacted forested regions of northeastern Ontario. The Canadian, international, peer-reviewed and grey literature was searched to identify a range of values for the soil quality parameters.
- It was ascertained that the values at the reference sites were within the range established in the previous step.
- Literature and reference values were used to determine numerical parameter ranges representing low to no impact; moderate impact; and severe impact for each soil quality parameter. These ranges were used for test site evaluation.

Test Site Evaluation

The following steps were taken to rank the test sites**:**

- Select the reference site(s) that was most appropriate for comparison with each test site, in terms of parent material composition, by comparing the physical properties of the reference site soils to those of the test sites.

- Compare soil quality parameter values for each test site to those of the appropriate reference site(s) using percent difference.

- Assign a preliminary parameter rank. Generally, parameters were ranked green if they fell within 25% of the value for the appropriate reference site(s). Parameter values 25 to 50% lower than those for the appropriate reference site(s) were ranked yellow, while values more than 50% lower were ranked red. If information on levels where deficiencies or excesses occur was available for a nutrient parameter it was incorporated into the preliminary parameter rank.

- Adjust the parameter ranks using expert judgment to ensure internal consistency (*i.e.*, to ensure that similar parameter values are given similar ranks across all sites) and obtain a final parameter rank.

- Prepare a retrospective ranking range table based on the parameter values and ranks for the test sites (Table GD-9-2-5.1). This table was used for a final check of the logic and consistency of the rankings.

- Assign a preliminary rank to each site based on the rank for the soil development category, then use expert judgment to adjust the preliminary rank according to the ranks for the other parameter categories (The overall ranking was assigned "blindly", meaning that all of the data was presented to the experts without revealing the site identification.)

The sites were placed into one of three categories:

Category		Description
G	High Quality Soil	The majority of the soil quality parameters at these sites fell within the "green" parameter range. The soil can be considered a good medium for plant growth
Y	Moderate Soil	The majority of the soil quality parameters at these sites fell within the "yellow" parameter range. Selected soil quality parameters appeared to be affecting the performance of the solum as a medium to promote plant growth.
R	Low Quality Soil	The majority of the soil quality parameters at these sites fell within the "red" parameter range. Some soil quality parameters appeared to be seriously impacting solum potential and were likely limiting plant growth.

GD-9-2-3.2 Soil Quality Parameters

Each of the following parameters was evaluated, and unless otherwise indicated, given a ranking for each site. It is important to note that the approach did not consider either the metal concentration or the pH of the soil during the ranking process. These two factors, although vital in determining soil conditions, were built into site selection, and therefore not considered in site ranking (see Chapter 3 of Volume III). Metals are the main focus of Objective #1 of the ERA and are considered during Step 2 and 3 of the site evaluation process (see Chapter 3 of Volume III for details). Soil pH is one of the most common and important measurements in standard soil analyses because many soil chemical and biological reactions are controlled by soil pH in equilibrium with the soil particle surfaces (Hendershot et al., 1993). The test and reference sites for this study were selected to ensure a pH range of between 4.0 and 5.0 in the 0–5 cm surface soil depth in an attempt to minimize the potential impact of pH variability in the toxicity assessment.

The rationale and background for each evaluated soil quality parameter is discussed in the following sections.

GD-9-2-3.2.1 Parent Material

The texture of the parent material controls the internal drainage class of the soils developed on them, which range from well drained on the coarser textured soils to imperfectly drained on the finer textured glaciolacustrine sites. Although these parameters are important from the perspective of soil development, they were not utilized in ranking because slope and texture, from which drainage class may be inferred, were used in the Plant Community Assessment Ranking Report. The parent material at each site was included and discussed as part of this assessment, but was not used as a ranking criterion.

GD-9-2-3.2.2 Soil Development

On many sites, the record of soil development has been affected by erosive events following removal of stabilizing vegetation (see Appendix GD5-1 for detailed description of Soil Pedon Layers). The pedon descriptions reflect these erosive impacts by documenting the variety of incomplete horizon sequences. The loss of the surface horizons by erosion implied a loss of organic matter, nutrients and stabilizing materials crucial for sustainable plant growth.

GD-9-2-3.2.3 Organic Matter

The amount of organic matter in soil is a function of the additions of fresh material and the decomposition rates. Despite the fact that plants do not require organic matter as such for their growth and development, it is considered one of the most important components of soil fertility because it influences a wide range of soil properties and processes (Gregorich et al, 1994, and Schroth 2003).

The quality of soil organic matter at each test site was ranked relative to baseline conditions documented in the reference sites. Key soil organic matter components evaluated included total carbon and nitrogen levels.

GD-9-2-3.2.4 Soil Exchange Complex Chemistry

This soil quality parameter was composed of the cation exchange capacity (CEC), Ca, Mg, the Ca:Mg ratio, and base saturation. Of these parameters, CEC was considered the strongest determinant of soil quality. Each of the parameters is discussed below:

Cation Exchange Capacity

Soil possesses electrostatic charges that counter exchangeable ions, and form the exchange complex. Some nutrients are positively charged (cations) while others are negatively charged (anions). The cation exchange capacity (CEC) is a measure of the amount of ions that can be absorbed, in an exchangeable fashion, on the negative charge sites of the soil (Bache, 1976; Carter, 1993). The ability of a soil to adsorb cations has very important implications for soil fertility (Schroth and Sinclair, 2003) and to its ability to sorb metals due to ion exchange ability (Lanno, 2003). CEC is important because it provides an indication of the ability of the soil to bind and retain nutrients. The higher the CEC of soils, the more ability the soil has to hold onto plant available soil nutrients and thus not to lose them through leaching (Schroth and Sinclair, 2003). This parameter is often reflective of the soil texture and colloidal organic matter contents of the site soil.

Calcium and Magnesium

Calcium and magnesium are macronutrients that are essential for plants. The Ca^{2+} ion and Mg^{2+} ion are chemically similar but there are important differences between them. The ratio of Ca to Mg is an important parameter because an optimum range is preferred by many plant species; values outside of this range are potentially growth limiting and/or toxic.

Base Saturation

The percentage base saturation was determined for the soil samples collected from all sites in the Sudbury region. Percent base saturation refers to the percent of the exchange sites that are occupied by the basic cations.

GD-9-2-3.2.5 Fertility

The 13 mineral nutrient elements plants require to complete their life cycle are referred to as essential plant nutrients. Each of these nutrients has a critical function and is required in varying amounts in plant tissue. Macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium and sulphur) are required in the largest amount in plants. Micronutrients (iron, copper, manganese, zinc, boron, molybdenum and chlorine) are required in relatively smaller amounts.

The overall fertility of the sites was evaluated by examining the concentrations of the macronutrients: nitrogen, phosphorus, potassium and magnesium; and of the micronutrients: iron and manganese. The macronutrients were considered stronger determinants of soil quality than the micronutrients.

Nitrogen

Nitrogen is the most limiting nutrient in plant growth. Soils rarely contain enough nitrogen for maximum plant growth (Troeh and Thompson, 2005). For nitrogen to be useful to higher plants, it must be chemically combined (fixed) with hydrogen, oxygen or carbon. Nitrogen fixation is accomplished by microorganisms, and 99% of nitrogen in soil is contained in the organic matter. Nitrogen is available in many different forms in the soil, including nitrate (NO^{3-}), ammonia (NH_4) and nitrite (NO^{2-}). Nitrite is seldom present at levels that exceed detection.

Phosphorous

Phosphorous is utilized in root and shoot development, nitrogen fixation and photosynthesis (Krishna, 2003; Ashman and Puri, 2002). It forms complex anions with oxygen, but most phosphates are nearly insoluble. The low solubility of phosphates is a severe limitation on its availability in soils.

Potassium

Plants require large quantities of potassium, mostly in the form of the K^+ ion. Most K^+ ions are highly soluble in water, and it is in this form that they are most available to plants. Potassium deficiency causes plants to be stunted.

Magnesium

Magnesium is an essential constituent of chlorophyll, is involved in seed information, and activates photosynthesis and certain enzyme reactions. Magnesium leaches relatively slowly, but the magnesium content of surface soil horizons can be depleted by severe weathering, soil erosion and clay eluviation (Troeh and Thompson, 2005).

Iron and Manganese

The levels of extractable iron and manganese were also evaluated and included in the fertility assessment. Iron deficiencies can result from an excess of either manganese or copper. Manganese and copper can serve as oxidizing agents and convert ferrous iron to the more insoluble ferric form. Iron deficiencies caused by manganese toxicity occur in acid soils that otherwise would probably supply adequate iron for plant growth (Troeh 2005).

GD-9-2-4.0 REFERENCE SITE EVALUATION

Before the reference sites could be used as a comparison to the test sites, various steps were undertaken to ensure that the physical and chemical conditions at the reference sites could be considered indicative of a typical northern Ontario forested area.

GD-9-2-4.1 Establishing "Typical" Range for Soil Quality Parameters at Unimpacted Forested Regions of North Eastern Ontario

A detailed literature review was first undertaken by researchers at Mirarco, Laurentian University. The report, provided by Mirarco, detailing background soil quality and fertility levels for typical northeastern Ontario forested sites is documented in Appendix GD-9-1

The literature review revealed a paucity of information related to the background soil chemical and physical conditions in the Sudbury region. The report concluded that, in comparison to the sites identified in the literature review, conditions at the Sudbury reference sites were within the ranges found in the literature review or were higher compared to other northeastern Ontario soils formed on similar parent materials with similar forest cover. Carbon and nitrogen data were limited for the literature review sites, but were generally lower at the reference sites than in the northeastern Ontario soils. For the majority of soil quality parameters, the values gleaned from this evaluation were considered indicative of baseline conditions in the region and formed one basis for the establishment of parameter ranges used to define different levels of impact. This comparison revealed that the values for most soil quality parameters at the reference sites were indicative of typical ranges for northern Ontario.

The literature review did not provide sufficient information on which to base parameter ranges associated with the three levels of impact for all the parameters chosen for the site evaluations.

Table GD-9-2-4.1 summarizes the comparison between the values measured at each of the reference sites to the typical values from the literature for healthy northeastern forest sites. The results reveal that overall, the three reference sites were within the range of values, indicating that the physical and chemical soil characteristics present at the sites were typical of forested areas of northeastern Ontario.

SARA GROUP

Table GD-9-2-4.1 Summary of Soil Quality Parameters for the Reference Sites

Reference Site Evaluation - Green

All reference sites were found to have good soil development and were not eroded. The organic matter levels were similar to those documented in the literature values for forested soil studies from the region. The cation exchange capacitiy and exchangable cation status was generally similar to that documented for the medium and coarser texture soils formed on the Canadian Shield-derived glaciogenic materials. The levels of Ca at REF-02 were slightly below the other reference sites. The fertility status of all of the reference sites was satisfactory and condusive to vigorous plant growth.

Parent Material Texture	The textural diversity of the parent material at the reference sites reflects the diversity of the glacigenic parent material of the region.			
Soil Development	The soil was well developed and not eroded.			
Reference Site	Ref-02	Ref-03	Ref-04	Comments
Organic Matter (g/100g)	G	G	G	
Total C	4.24	7.0	4.72	The organic matter was adequate at all reference sites. There may have been a significant amount of mineral soil in the sample.
Total N	0.23	0.23	0.34	
C:N Ratio	18	30	14	
Soil Exchange Complex Chemistry (cmol(+)/kg)	Y	G	G	
Cation Exchange Capacity	27.4	29.1	28.5	The potential excess of protons at REF-02 is perhaps indicative of acid rain influence. It could be that the parent material had a low amount of exchangeable Ca and Mg.
Calcium	0.38	2.8	0.78	
Magnesium	0.18	0.72	0.26	
Ca:Mg Ratio	2.1	3.9	3	
Base saturation (%)	2.72	13.06	4.42	
Fertility (mg/kg)	G	G	G	
N as Ammonium	3.45	2.9	0.45	The fertility status of all of the reference sites was satisfactory and condusive to vigorous plant growth.
Extractable P	17	20	8	
Extractable K	94	123	68	
Extractable Fe	1232.5	1256.2	918.9	
Extractable Mn	37.6	40.3	102.5	
Fe:Mn	32.8	31.2	9.0	
Extractable Mg	28	94	25	

GD-9-2-5.0 TEST SITE EVALUATION

Each of the 18 test sites was evaluated to determine an overall impact rank. CON-07, the historically limed and re-greened site was also evaluated but served only as a means of comparison and was not included in the overall site ranking. A soil scientist with experience in the Sudbury region (Dr. Graeme Spiers, MIRARCO, Laurentian University) evaluated the site results and gave each site its final rank. To do this, the soil quality parameters values at each of the test sites were compared to the reference sites. Only the reference site(s) that had similar parent material were compared to each test site. As the reference sites differed in soil physical properties, not all sites were compared to the same reference sites. The ranking tables indicate which reference sites were used to determine the soil LOE ranking. A preliminary parameter rank of green was assigned if the value fell within 25% of the value for the appropriate reference site(s). Parameter values 25 to 50% lower than those for the appropriate reference site(s) were ranked yellow, while values more than 50% lower were ranked red. If information on plant growth requirements for nutrient parameters was available then it was incorporated into the preliminary parameter rank. The preliminary parameter ranks were adjusted, as needed, using expert judgment to ensure internal consistency. Because sites may have been compared to different reference site(s), two sites with similar values for a parameter may have been assigned different preliminary parameter ranks. The adjustment ensures that similar parameter values were given similar ranks across all sites.

Based on all of the data available (*i.e.*, the literature values, the parameter values and ranks for the reference sites, and the parameter values and ranks for the test sites) a retrospective soil chemistry ranking range table was prepared (Table GD-9-2-5.1). The table was used for a final check of the logic and consistency of the rankings. Double-checking the site values against the parameter ranges increased confidence in the evaluation process.

Table GD-9-2-5.1 Definition of Soil Chemistry Ranges for Test Site Evaluation and Ranking

Rank	Low Quality Soil	Moderate Quality Soil	*High Quality Soil*
Organic Matter (g/100g)			
Total C	<3	3-3.9	>3.9
Total N	<0.1	0.11–0.21	>0.22
Soil Exchange Complex Chemistry (cmol(+)/kg)			
Cation Exchange Capacity	<19	20–24	>25
Calcium	<0.24	0.25–0.39	>0.4
Magnesium	<0.1	0.1–0.15	>0.15
Ca:Mg Ratio	<1.4	1.5–2.9 or >6	3–5.9
Base saturation (%)	<1.9	2–4.9	>5
Fertility (mg/kg)			
N as Ammonium	<0.19	0.2–0.39	>0.4
Extractable P	<5	5–7.9	>8
Extractable K	<44	45–64	>65
Extractable Fe	<499	500–749 or >1800	750–1800
Extractable Mn	<10	10–24 or >200	25–200
Fe:Mn	<5	5–14 or >50	15–50
Extractable Mg	<15	15–25	>25

Finally, Dr. Spiers assigned a preliminary rank to each site based on the rank for the soil development category, then use expert judgment to adjust the preliminary rank according to the ranks for the other parameter categories. This overall ranking was done “blindly”, meaning that Dr. Spiers was not aware of the site identification when ranking was determined, to control any associated bias. A summary of the final LOE ranking for each test site is shown in Table GD-9-2-5.2 and in Figure GD-9-2-5.1.

The results from each test site are provided in the series of tables that follow. Site ranking is primarily based on driving values that have been identified in bold in the tables below.

Table GD-9-2-5.2 Summary of Overall Soil Characterization LOE Ranking for Test Sites

Site	Rank
CC-01	Y
CC-02	R
CC-03	R
CC-04	Y
CC-06	Y
CC-07	Y
CC-08	Y
CON-01	Y
CON-02	R
CON-03	Y
CON-05	Y
CON-06	Y
CON-07*	Y
CON-08	R
FB-01	Y
FB-02	G
FB-03	Y
FB-05	Y
FB-06	G

* CON-07, the historically limed and re-greened site, was ranked at the LOE level, but was not given an overall site rank

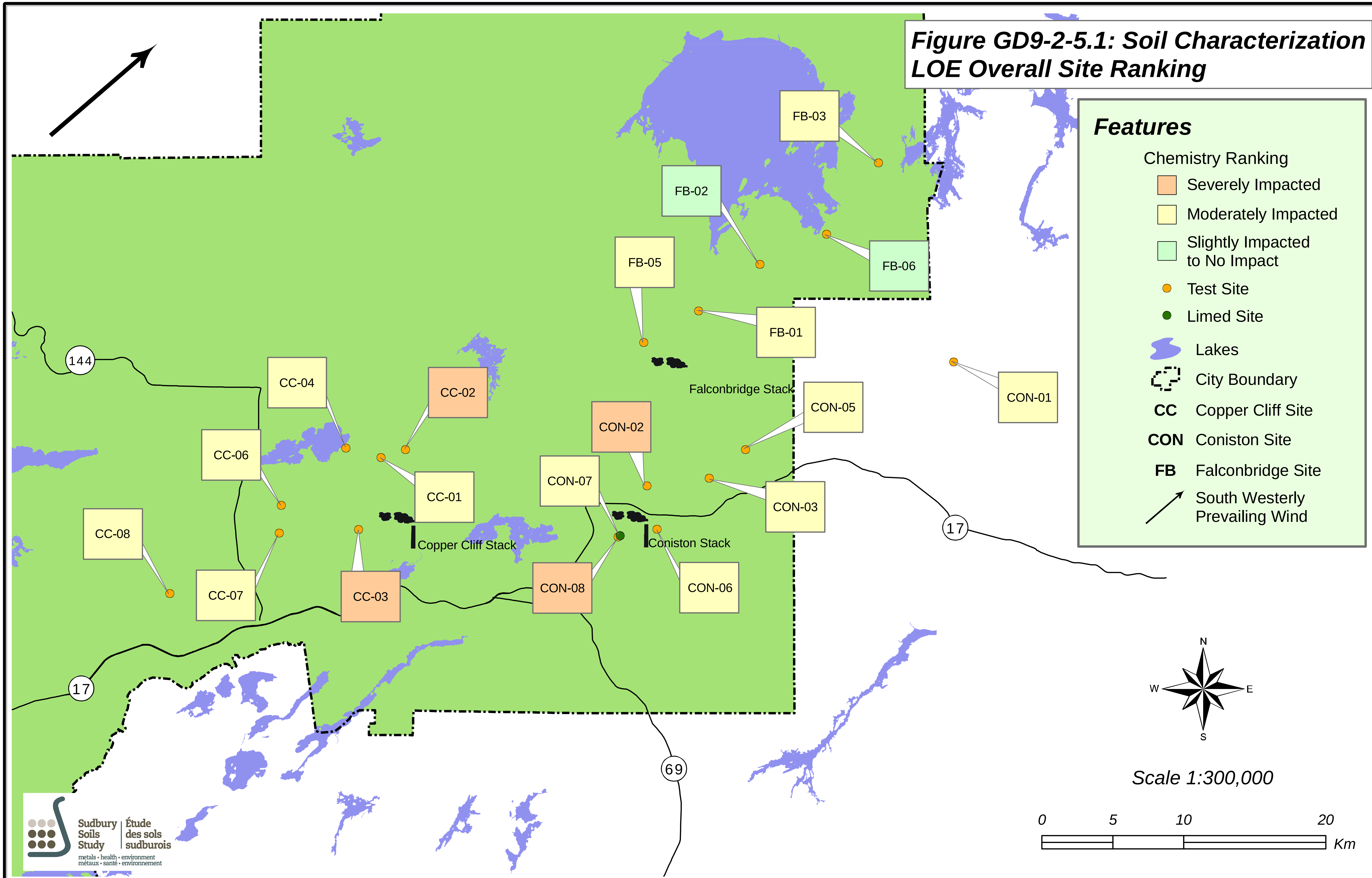

Figure GD9-2-5.1: Soil Characterization LOE Overall Site Ranking

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CC-01: Ranked Moderately Impacted			**Y**
The site had eroded relict soil sub-surface horizons exposed as the growing medium. Although the organic matter content was relatively high and was similar to the reference sites, the lack of stable organic and mineral horizons affected the site fertility and suitability as a growth medium. The site was poorer than the reference sites in terms of some fertility parameters			
Parent Material Texture			Because the site was most similar to REF-03 and REF-02 in terms of texture, all site comparisons were made to these two reference sites.
Step A: Soil Development			**R**
The site was eroded relative to the reference sites. There was no residual LFH or A horizons.			
Step B: Organic Matter (g/100g)			**G**
Total C	4.46	G	The total carbon was similar to REF-02 and lower than REF-03.
Total N	0.26	G	The total nitrogen was similar to REF-02 and REF-03 .
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**G**
Cation Exchange Capacity	**28.8**	**G**	**The CEC was similar to both reference sites.**
Calcium	2.1	G	The exchangeable calcium was higher than REF-02 but lower than REF-03.
Magnesium	0.27	G	The exchangeable magnesium was similar to REF-02 but lower than REF-03.
Ca:Mg Ratio	7.8	Y	The Ca:Mg ratio was higher than both reference sites, suggesting that Mg may be leaching from the system.
Base saturation (%)	9.06	G	The base saturation was higher than at REF-02, and lower than REF-03.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**11.54**	**G**	**The extractable ammonium was higher than both reference sites.**
Extractable P	**19.0**	**G**	**The extractable phosphorus was similar to both reference sites.**
Extractable K	**29.0**	**R**	**The extractable potassium was lower than both REF-02 and REF-03, indicating that there was potentially less K available and**
Extractable Fe	1210.7	G	The iron was similar to the levels at the reference sites, while the manganese was higher. Consequently, the ratio was lower than the reference sites.
Extractable Mn	70.4	G	
Fe:Mn	17.2	G	
Extractable Mg	**7.0**	**R**	**The extractable Mg was lower than either reference site, suggesting that the site may be deficient in magnesium.**

CC-02: Ranked Severely Impacted			R
The site was not eroded and consequently the regional mature soil at this site was Eluviated Dystric Brunisol. The coarser soil texture at this site indicated that the moisture holding capacity was reduced. The soil contained adequate organic carbon but lower total and available nitrogen, and was deficient in both available Mg, K and N. Several fertility parameters were found to be deficient relative to the reference sites.			
Parent Material Texture			This site was sandier than all of the reference sites and therefore had a lower moisture holding capacity. Because no particular reference site formed a close match, this site was compared to all three reference sites.
Step A: Soil Development			G
The soil was well developed and was not eroded.			
Step B: Organic Matter (g/100g)			Y
Total C	2.29	R	The total carbon was lower than the reference sites.
Total N	0.13	Y	The total nitrogen was lower than the reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			Y
Cation Exchange Capacity	**16.8**	**R**	**The CEC was lower than the reference sites.**
Calcium	0.3	Y	The exchangeable calcium was lower than the reference sites.
Magnesium	0.05	R	The exchangeable magnesium was lower than the reference sites.
Ca:Mg Ratio	6	Y	The Ca:Mg ratio was higher than the reference sites, suggesting that magnesium at the site could be deficient.
Base saturation (%)	2.6	Y	The base saturation was similar to REF-02 but was lower than REF-03 and REF-04.
Step B: Fertility (mg/kg)			R
N as Ammonium	**0.07**	**R**	**The extractable ammonium was lower than the reference sites.**
Extractable P	**23.0**	**G**	**The extractable phosphorus was similar to REF-02 and REF-O3, and higher than REF-04.**
Extractable K	**42.0**	**R**	**The extractable potassium was lower than the reference sites.**
Extractable Fe	861.1	G	The iron was lower than the levels at the reference sites.
Extractable Mn	45.1	G	The manganese was similar to REF-02 and REF-03 but lower than REF-04.
Fe:Mn	19.1	G	The Fe:Mn ratio was lower than REF-02 and REF-03 but higher than REF-04.
Extractable Mg	**11.0**	**R**	**The extractable magnesium was lower than the reference sites, suggesting that the site may be deficient in magnesium.**

CC-03: Ranked Severely Impacted			R
The site was eroded with relict soil sub-surface horizons exposed as the growing medium. Although the organic matter content was relatively high and was similar to the reference sites, the lack of stable surface organic and mineral horizons affected the site fertility and suitability as a growth medium. The site did appear to be altered relative to the reference sites in terms of fertility parameters and exchange chemistry.			
Parent Material Texture			Because the soil texture at this site was most similar to REF-03 and REF-02 in terms of texture, all site comparisons were made to these two reference sites.
Step A: Soil Development			**R**
The site was eroded relative to the reference sites, and there was no residual LFH or A horizons.			
Step B: Organic Matter (g/100g)			**G**
Total C	4.62	G	The total carbon was similar to REF-02 and lower than REF-03.
Total N	0.22	G	The total nitrogen was similar to REF-02 and REF-03.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**20.8**	**Y**	**The CEC was lower than both REF-02 and REF-03.**
Calcium	0.33	Y	The exchangeable calcium was similar to REF-02, but lower than REF-03.
Magnesium	0.05	R	The exchangeable magnesium was lower than both reference sites.
Ca:Mg Ratio	6.6	Y	The Ca:Mg ratio was higher than the reference sites suggesting that Mg has been leached out of the system.
Base saturation (%)	2.62	Y	The base saturation was similar to REF-02, but lower than REF-03, suggesting that this site may be depleted in base cations.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**1.5**	**G**	**The extractable ammonium was lower than REF-02 and REF-03 but still within a reasonable range.**
Extractable P	**28.0**	**G**	**The extractable phosphorus was higher than REF-02 and REF-03.**
Extractable K	**28.0**	**R**	**The extractable potassium was lower than both REF-02 and REF-03.**
Extractable Fe	1864.1	Y	The iron was higher than REF 02 and REF-03, but the manganese was lower. The Fe:Mn ratio was higher than the reference sites, which may indicate a higher bioavailability of iron.
Extractable Mn	19.1	Y	
Fe:Mn	97.6	Y	
Extractable Mg	**12.0**	**R**	**The extractable magnesium was lower than REF-02 and REF-03, suggesting the site may be deficient in available magnesium.**

CC-04: Ranked Moderately Impacted			Y
This uneroded site had organic matter levels that were similar to the reference sites. Some of the fertility parameters (e.g. Ca and Mg) were found to be deficient.			
Parent Material Texture			Because the soil texture at this site was most similar to REF-03 and REF-02 in terms of texture, all site comparisons were made to these two reference sites.
Step A: Soil Development			G
This soil, with higher silt and clay contents than the reference sites, was relatively well developed with good internal soil drainage and potentially higher moisture holding capacity, making it potentially less prone to desiccation. The site was not eroded, and the soil was typical of many Eluviated Dystric Brunisols within the Sudbury region.			
Step B: Organic Matter (g/100g)			G
Total C	5.19	G	The total carbon was similar to both reference sites.
Total N	0.3	G	The total nitrogen was similar to both reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			G
Cation Exchange Capacity	**18.5**	**R**	**The CEC was lower than both reference sites.**
Calcium	1.4	G	The exchangeable calcium was higher than REF-02 but lower than REF-03.
Magnesium	0.3	G	The exchangeable magnesium was higher than REF-02 but lower than REF-03.
Ca:Mg Ratio	4.7	G	The Ca:Mg ratio and base saturation were higher than both reference sites suggesting the presence of higher levels of extractable base cations.
Base saturation (%)	10.8	G	
Step B: Fertility (mg/kg)			Y
N as Ammonium	**1.2**	**G**	**The extractable ammonium was lower than either of the reference sites.**
Extractable P	**43.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**47.0**	**Y**	**The extractable potassium was lower than the reference sites.**
Extractable Fe	1495.1	G	The extractable iron was higher than the reference sites.
Extractable Mn	205.6	Y	The extractable maganese was higher than the reference sites.
Fe:Mn	7.3	Y	The Fe:Mn ratio was lower than the reference sites.
Extractable Mg	**11.0**	**R**	**The extractable magnesium was lower than either reference site, suggesting that the site may be deficient in magnesium.**

CC-06: Ranked Moderately Impacted			**Y**
With the well developed LFH horizons, soils at this site contained adequate organic matter for seedling development and growth. However, there was some evidence for potential magnesium and available nitrogen deficiency.			
Parent Material Texture			The soil texture at this site was most similar to REF-03 and REF-02. All site comparisons were made to these two reference sites.
Step A: Soil Development			**G**
The soil developed on this non-eroded site was an Eluviated Dystric Brunisol, and is typical of some of the modal soils in the Sudbury area. With the well developed LFH horizons, soils at this site contained adequate organic matter for seedling development and growth.			
Step B: Organic Matter (g/100g)			**Y**
Total C	3.11	Y	The total carbon was lower than REF-02 and REF-03.
Total N	0.22	G	The total nitrogen was similar to both reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**49.5**	**G**	**The CEC was higher than both reference sites.**
Calcium	0.31	Y	The exchangeable calcium was lower than REF-02 and REF-03.
Magnesium	0.05	R	The exchangeable magnesium was lower than both reference sites.
Ca:Mg Ratio	6.2	Y	The Ca:Mg ratio was higher than at both reference sites, suggesting the site may be depleted in magnesium.
Base saturation (%)	1	R	The base saturation was lower than the reference sites.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**0.01**	**R**	**The ammonium was lower than both of the reference sites.**
Extractable P	**57.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**67.0**	**G**	**The extractable potassium was lower than the reference sites.**
Extractable Fe	1434.5	G	The extractable iron was higher than the reference sites.
Extractable Mn	107.2	G	The extractable manganese was higher than the reference sites.
Fe:Mn	13.4	Y	The Fe:Mn ratio was lower than the reference sites.
Extractable Mg	**21.0**	**Y**	**The extractable Mg was lower than REF-02 and REF-03 suggesting that the site may be deficient in Mg.**

CC-07: Ranked Moderately Impacted			**Y**
With the well developed LFH horizons, soils at this uneroded site contained adequate organic matter for seedling development and growth. However, there was some evidence for potential magnesium and available nitrogen deficiency.			
Parent Material Texture			The parent material of this soil had more clay than REF-02 and REF-03 and thus may have an improved moisture holding capacity. However, the overall silt loam texture was similar to REF-02 and REF-03. All site comparisons were made to these two reference sites.
Step A: Soil Development			**G**
The relatively well developed soil on this non-eroded site is an Orthic Humo-Ferric podzol. The development of fine manganese mottles in the C horizon of this soil further supports the suggestion of potentially higher moisture holding capacity.			
Step B: Organic Matter (g/100g)			**G**
Total C	5.05	G	The total carbon was similar to REF-02 and lower than REF-03.
Total N	0.26	G	The total nitrogen was similar to both reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**G**
Cation Exchange Capacity	**21.3**	**Y**	**The CEC was lower than both reference sites.**
Calcium	0.69	G	The exchangeable calcium was higher than REF-02 but lower than REF-03.
Magnesium	0.16	G	The exchangeable magnesium was similar to REF-02 but lower than REF-03.
Ca:Mg Ratio	4.3	G	The Ca:Mg ratio was higher than the reference sites.
Base saturation (%)	5.14	G	The base saturation was higher than REF-02 and lower than REF-03.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**0.08**	**R**	**The extractable ammonium was lower than either of the reference sites.**
Extractable P	**44.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**77.0**	**G**	**The extractable potassium was similar to REF-02 and lower than REF-03.**
Extractable Fe	1497.3	G	The extractable iron was higher than the reference sites.
Extractable Mn	101.1	G	The extractable manganese was higher than the reference sites.
Fe:Mn	14.8	Y	The Fe:Mn ratio was lower than the reference sites.
Extractable Mg	**18.0**	**Y**	**The extractable magnesium was lower than the reference sites suggesting that the site may potentially be deficient in Mg.**

CC-08: Ranked Moderately Impacted			**Y**
With the well developed LFH horizons, soils at this uneroded site contained adequate organic matter for seedling development and growth. However, there was some evidence for potential magnesium and available nitrogen deficiency.			
Parent Material Texture			The silt loam stony till at this site was similar in texture to REF-02 and REF-03. All site comparisons were made to these two reference sites.
Step A: Soil Development			**G**
The Eluviated Dystric Brunisol developed on this uneroded site was typical of many of the well-drained modal pedons of the Sudbury region.			
Step B: Organic Matter (g/100g)			**G**
Total C	5.59	G	The total carbon was higher than REF-02 and lower than REF-03.
Total N	0.24	G	The total nitrogen was similar to both reference sites
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**52.1**	**G**	**The CEC was higher than both reference sites, reflecting a high level of organic matter in the sample.**
Calcium	0.15	R	The exchangeable calcium was lower than both reference sites.
Magnesium	0.05	R	The exchangeable magnesium was lower than both reference sites.
Ca:Mg Ratio	3	G	The Ca:Mg ratio was higher than REF-02 and lower than REF-03.
Base saturation (%)	0.68	R	The base saturation was lower than both reference soils.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**0.61**	**G**	**The extractable ammonium was lower than the reference sites.**
Extractable P	**42.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**64.0**	**Y**	**The extractable potassium was lower than REF-02 and REF-03 .**
Extractable Fe	1739.1	G	The extractable iron was higher than the reference sites.
Extractable Mn	23.2	Y	The extractable manganese was lower than the reference sites.
Fe:Mn	75.0	Y	The Fe:Mn ratio was higher than either of the reference sites.
Extractable Mg	**14.0**	**R**	**The extractable magnesium was lower than the reference sites suggesting that the site may be deficient in Mg.**

CON-01: Ranked Moderately Impacted			Y
Although this site was ranked low to not impacted, historical fire has effected the nature of the organic matter and the surface organic horizons. The site may also be deficient in available nitrogen, potassium and magnesium.			
Parent Material Texture			This fine sandy loam glacio-fluvial parent material was similar in texture to REF-02 and REF-03. All site comparisons were made to these two reference sites.
Step A: Soil Development			G
This well developed shallow Pozolic soil was typical of another of the modal soils of the Sudbury region. Although the site appeared to be uneroded, there was abundant evidence of fire, with abundant charcoal fragments in the LFH horizons.			
Step B: Organic Matter (g/100g)			Y
Total C	3.07	Y	The total carbon was lower than REF-02 and REF-03.
Total N	0.12	Y	The total nitrogen was lower than REF-02 and REF-03.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			G
Cation Exchange Capacity	**28.5**	**G**	**The CEC was similar to both REF-02 and REF-03.**
Calcium	1.8	G	The exchangeable calcium was higher than REF-02 and lower than REF-03.
Magnesium	0.51	G	The exchangeable magnesium was higher than REF-02 and lower than REF-03.
Ca:Mg Ratio	3.5	G	The Ca:Mg ratio is higher than REF-02 and similar to REF-03.
Base saturation (%)	9.5	G	The base saturation is higher than REF-02 and lower than REF-03.
Step B: Fertility (mg/kg)			Y
N as Ammonium	**1.82**	**G**	**The extractable ammonium was lower than REF-02 and lower than REF-03.**
Extractable P	**19.0**	**G**	**The extractable phosphorus was similar to both REF-02 and REF-03.**
Extractable K	**29.0**	**R**	**The extractable potassium was lower than REF-02 and lower than REF-03.**
Extractable Fe	1461.7	G	The extractable iron was higher than both REF-02 and REF-03.
Extractable Mn	108.6	G	The extractable manganese was higher than both REF-02 and REF-03.
Fe:Mn	13.5	Y	The Fe:Mn ratio was lower than both REF-02 and REF-03, suggesting potential manganese excess.
Extractable Mg	**7.0**	**R**	**The extractable magnesium was lower than the reference sites.**

CON-02: Ranked Severely Impacted			R
The soils at this highly impacted eroded site were low in surface organic matter, deficient in nutrients, and would be subject to freeze-thaw processes which would injure regeneration.			
Parent Material Texture	The soil at this site was formed in a silt loam glacio-ecustran parent material, texturally similar to REF-03 and REF-02. All site comparisons were made to these two reference sites. If unvegetated, this material would be very prone to water erosion.		
Step A: Soil Development			Y
The Glayd-Grey Luvisol at this eroded site had no surface LFH Horizon characteristic of these modal soils. The presence of mottles in the Btg Horizon is indicative of a seasonally wet soil.			
Step B: Organic Matter (g/100g)			R
Total C	1.05	R	The total carbon was lower than both REF-02 and REF-03.
Total N	0.04	R	The total nitrogen was lower than both REF-02 and REF-03.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			R
Cation Exchange Capacity	**24**	**Y**	**The CEC was lower than REF-02 and REF-03.**
Calcium	0.11	R	The exchangeable calcium was lower than both REF-02 and REF-03.
Magnesium	0.05	R	The exchangeable magnesium was lower than both REF-02 and REF-03.
Ca:Mg Ratio	2.2	Y	The Ca:Mg ratio was similar to REF-02 and lower than REF-03.
Base saturation (%)	1.31	R	The base saturation was lower than both REF-02 and REF-03.
Step B: Fertility (mg/kg)			Y
N as Ammonium	**0.01**	**R**	**The extractable ammonium was lower than both REF-02 and REF-03.**
Extractable P	**23.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**42.0**	**R**	**The extractable potassium was lower than both REF-02 and REF-03.**
Extractable Fe	1358.9	G	The extractable iron was higher than both REF-02 and REF-03.
Extractable Mn	27.3	G	The extractable manganese was lower than REF-02 and REF-03.
Fe:Mn	49.8	G	The Fe:Mn ratio was higher than both REF-02 and REF-03.
Extractable Mg	**11.0**	**R**	**The extractable magnesium was lower than both REF-02 and REF-03.**

CON-03: Ranked Moderately Impacted			**Y**
The imperfectly drained soils at this moderately eroded site did not have and adequate LFH horizon for seedling germination and growth. Although the relict mineral soil horizons were well developed and have a relatively high clay content, there was a potential available nitrogen deficiency at this site.			
Parent Material Texture	The fine silt loam glacial ecustrian material had more clay than most of the sites examined in this project. The texture was most similar to REF-04. Although not as similar in soil texture, comparisons to REF-02 and REF-03 were also included. If unvegetated, this material would be very prone to water erosion.		
Step A: Soil Development			**Y**
Although there were well developed relict mineral soil horizons, the surface organic (LFH) horizons had been eroded from the pedons at this site.			
Step B: Organic Matter (g/100g)			**Y**
Total C	3.75	Y	The total carbon was similar to REF-02, lower than REF-04 and lower than REF-03.
Total N	0.22	G	The total nitrogen was similar to REF-02 and REF-03, and lower than REF-04.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**15.7**	**R**	**The CEC was lower than the reference sites, reflecting the lower organic carbon content.**
Calcium	0.74	G	The exchangeable calcium was higher than REF-02, lower than REF-03 and similar to REF-04.
Magnesium	0.28	G	The exchangeable magnesium was higher than REF-02, lower than REF-03 and similar to REF-04.
Ca:Mg Ratio	2.6	Y	The Ca:Mg ratio was similar to the REF-02 and slightly lower than REF-03 and REF-04.
Base saturation (%)	7.92	G	The base saturation was higher than REF-02 and REF-04, and lower than REF-03.
Step B: Fertility (mg/kg)			**G**
N as Ammonia	**0.42**	**G**	**The extractable ammonium was lower than REF-02 and REF-03, and similar to REF-04.**
Extractable P	**60.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**110.0**	**G**	**The ex tractable potassium was higher than REF-04 and similar to REF-02 and REF-03.**
Extractable Fe	2442.7	Y	The extractable iron was higher than the reference sites.
Extractable Mn	98.4	G	The extractable manganese was higher than REF-02 and REF-03, and similar to REF-04.
Fe:Mn	24.8	G	The Fe:Mn ratio was lower than REF-02 and REF-03, and higher than REF-04.
Extractable Mg	**35.0**	**G**	**The extractable magnesium was higher than REF-04, similar to REF-02 and lower than REF-03.**

CON-05: Ranked Moderately Impacted			Y
The imperfectly drained soils at this moderately eroded site did not have and adequate LFH horizon for seedling germination and growth. Although the relict mineral soil horizons were well developed and had a relatively high clay content, there was a potential available nitrogen deficiency at this site. The differences in extractable iron and manganese may also indicate a potential problem.			
Parent Material Texture			The fine silt loam glacial ecustrian material had more clay than most of the sites examined in this project. The texture was most similar to REF-04. Although not as similar in soil texture, comparisons to REF-02 and REF-03 were also included. If unvegetated, this material would be very prone to water erosion.
Step A: Soil Development			Y
Although there were well developed relict mineral soil horizons, the surface organic (LFH) horizons had been eroded from the pedons at this site.			
Step B: Organic Matter (g/100g)			Y
Total C	3.51	Y	The total carbon was lower than the reference sites.
Total N	0.27	G	The total nitrogen was lower than REF-04 and similar to REF-02 and REF-03.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			Y
Cation Exchange Capacity	**45.4**	**G**	**The CEC was higher than all three reference sites, reflecting the high clay content at this site.**
Calcium	0.25	Y	The exchangeable calcium was lower than all three reference sites.
Magnesium	0.05	R	The exchangeable magnesium was lower than the reference sites.
Ca:Mg Ratio	5	G	The Ca:Mg ratio was higher than the reference sites.
Base saturation (%)	1.41	R	The base saturation was lower than all three reference sites.
Step B: Fertility (mg/kg)			Y
N as Ammonium	**0.03**	**R**	**The extractable ammonium was lower than all three reference sites.**
Extractable P	**43.0**	**G**	**The extractable phosphorus was higher than all three reference sites.**
Extractable K	**156.0**	**G**	**The extractable potassium was higher than the reference sites.**
Extractable Fe	1872.7	Y	The extractable iron was higher than the reference sites
Extractable Mn	14.3	Y	The extractable manganese was lower than all three reference sites.
Fe:Mn	131.0	Y	The Fe:Mn ratio was higher than all three reference sites.
Extractable Mg	**72.0**	**G**	**The extractable magnesium was higher than REF-04 and REF-02 and lower than REF-03.**

CON-06: Ranked Moderately Impacted			**Y**
The imperfectly drained soils at this moderately eroded site did not have and adequate LFH horizon for seedling germination and growth. Although the relict mineral soil horizons were well developed, there was a very low organic carbon content. The Ca:Mg ratio was lower than most sites in this study, suggesting a potential nutrient imbalance.			
Parent Material Texture	The fine silt loam glacial ecustrian material had an equivalent amount of clay to REF-02 and REF-03, but more silt and less sand. REF-04 had significantly more clay and less sand. Comparisons were made to all three reference sites. If unvegetated, this material would be very prone to water erosion.		
Step A: Soil Development			**Y**
The shallow, imperfectly drained luvisolic pedon at CON-06 was eroded, with no organic rich LFH horizons.			
Step B: Organic Matter (g/100g)			**R**
Total C	0.46	R	The total carbon was lower than all three reference sites.
Total N	0.07	R	The total nitrogen was lower than all three reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**11**	**R**	**The CEC was lower than all three reference sites.**
Calcium	0.51	G	The exchangeable calcium was lower than REF-03 and REF-04, and higher than REF-02.
Magnesium	0.26	G	The exchangeable magnesium was similar to REF-04, higher than REF-02 and lower than REF-03.
Ca:Mg Ratio	2	Y	The Ca:Mg ratio was lower than REF-03 and REF-04, and similar to REF-02.
Base saturation (%)	8.4	G	Base saturation was higher than REF-04 and REF-02 and lower than REF-03.
Step B: Fertility (mg/kg)			**G**
N as Ammonium	**3.19**	**G**	**The extractable ammonium was higher than REF-04, and similar to REF-02 and REF-03.**
Extractable P	**57.0**	**G**	**The extractable phosphorus was higher than all reference sites.**
Extractable K	**67.0**	**G**	**The extractable potassium was similar to REF-04, and lower than REF-02 and REF-03.**
Extractable Fe	221.7	R	The extractable iron was lower than all three reference sites.
Extractable Mn	12.3	Y	The extractable manganese was lower than all three reference sites.
Fe:Mn	18.0	G	The Fe:Mn ratio was higher than REF-04, and lower than REF-02 and REF-03.
Extractable Mg	**21.0**	**Y**	**The extractable magnesium was similar to REF-04 and REF-02, and lower than REF-03.**

CON-07*: Ranked Moderately Impacted			**Y**
This site had been limed and cultivated, and the effects of this reclamation process were obvious. However, the imperfectly drained soils at this moderately eroded site showed minimal redevelopment of the regionally important LFH horizons. Although the relict mineral soil horizons were well developed, there was a very low organic carbon content. The Ca:Mg ratio in the surface soil was in balance because of the liming program.			
Parent Material Texture			The fine silt loam glacial ecustrian material had an equivalent amount of clay to REF-02 and REF-03, but more silt and less sand. REF-04 had significantly more clay and less sand. Comparisons were made to all three reference sites. If unvegetated, this material would be very prone to water erosion.
Step A: Soil Development			**Y**
The soil development at this limed site was anomalous, as is evidenced by the development of a thin Ah horizon, the product of cultivation and introduced organism activity. The relict sub surface mineral horizons, low in organic matter, are representative of those found on the balance of the Coniston sites.			
Step B: Organic Matter (g/100g)			**R**
Total C	1.83	R	The total carbon was lower than all three reference sites.
Total N	0.09	R	The total nitrogen was lower than all three reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**14.6**	**R**	**The CEC was lower than all three reference sites.**
Calcium	9.4	G	The exchangeable calcium was higher than all three reference sites.
Magnesium	1.3	G	The exchangeable magnesium was higher than all three reference sites.
Ca:Mg Ratio	7.2	G	The Ca:Mg ratio was higher than all three reference sites.
Base saturation (%)	73	G	The base saturation was higher than all three reference sites.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**0.68**	**G**	**The extractable ammonium was higher than REF-04, and lower than both REF-02 and REF-03.**
Extractable P	**7**	**Y**	**The extractable phosphorus was similar to REF-04, and lower than REF-02 and REF-03.**
Extractable K	**68**	**G**	**The extractable potassium was similar to REF-04, and lower than REF-02 and REF-03.**
Extractable Fe	321	R	The extractable iron was lower than all three reference sites.
Extractable Mn	38.3	G	The extractable manganese was lower than REF-04, and similar to REF-02 and REF-03.
Fe:Mn	8.5	Y	The Fe:Mn ratio was similar to REF-04 and lower than both REF-02 and REF-03.
Extractable Mg	**227**	**G**	**The extractable magnesium was higher than all three reference sites.**

* CON-07, the historically limed and re-greened site, was ranked at the LOE level, but was not given an overall site rank.

CON-08: Ranked Severely Impacted			**R**
The imperfectly drained soils at this highly eroded site did not have an adequate LFH horizon for seedling germination and growth. The surface mineral soil horizons (Ae) were also completely eroded from this site. The structural integrity of the remaining mineral horizons at this site was very poor. The Ca:Mg ratio was lower than most sites in this study, suggesting a potential nutrient imbalance. This site was also low in both available nitrogen and magnesium.			
Parent Material Texture			The texture was similar to REF-02 and REF-03, but with a higher amount of clay and less sand. All comparisons were made to these two reference sites.
Step A: Soil Development			**R**
This was a highly eroded site, with a shallow relict B horizon only over the parent material. Ped structural integrity was very weak, potentially breaking to a fine powder when dry.			
Step B: Organic Matter (g/100g)			**R**
Total C	0.82	R	The total carbon was lower than both REF-02 and REF-03.
Total N	0.03	R	The total nitrogen was lower than both REF-02 and REF-03.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**11.1**	**R**	**The CEC was lower than both reference sites.**
Calcium	0.82	G	The exchangeable calcium was higher than REF-02 and lower than REF-03.
Magnesium	1	G	The exchangeable magnesium was higher than both reference sites.
Ca:Mg Ratio	0.8	R	The Ca:Mg ratio was lower than both REF-02 and REF-03.
Base saturation (%)	18	G	The base saturation was higher than both reference sites.
Step B: Fertility (mg/kg)			**R**
N as Ammonium	**0.01**	**R**	**The extractable ammonium was lower than both reference sites.**
Extractable P	**42.0**	**G**	**The extractable phosphorus was higher than both reference sites.**
Extractable K	**64.0**	**Y**	**The extractable potassium was lower than the reference sites.**
Extractable Fe	547.2	Y	The extractable iron was lower than both reference sites.
Extractable Mn	28.0	G	The extractable manganese was lower than both REF-02 and REF-03.
Fe:Mn	19.5	G	The Fe:Mn ratio was lower than REF-03 and REF-02.
Extractable Mg	**14.0**	**R**	**The extractable magnesium was lower than REF-02 and REF-03.**

FB-01: Ranked Moderately Impacted			**Y**
The Pozolic soil at this site was typical of the modal soils on the glacio-fluvial outwash within the Sudbury region. These soils generally have a relatively low moisture holding capacity. Although this site was not eroded, the amount of charcoal in the LFH horizon was indicative of a high intensity fire in the recent past. The relatively high fertility on this site may be a reflection of an increase in nutrient availability from the surface organic layers following the historical fire.			
Parent Material Texture	The loam glacio-fluvial outwash soil parent material at this site was most similar to REF-03 and REF-02. All site comparisons were made to these two reference sites.		
Step A: Soil Development			**G**
The podzolic mineral soil horizons at this site were not eroded. However, the presence of charcoal in the very thin LFH indicated a severe burn or high intensity fire in the recent past.			
Step B: Organic Matter (g/100g)			**Y**
Total C	6.05	G	The total carbon was higher than REF-02 and similar to REF-03
Total N	0.1	R	The total nitrogen was lower than the reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**124**	**G**	**The CEC was higher than both reference sites, perhaps reflective of the high charcoal content of the surface organic layers.**
Calcium	0.24	R	The exchangeable calcium was lower than both reference sites.
Magnesium	0.05	R	The exchangeable magnesium was lower than both reference sites.
Ca:Mg Ratio	4.8	G	The Ca:Mg ratio was higher than the reference sites.
Base saturation (%)	0.37	R	The base saturation was lower than the reference sites.
Step B: Fertility (mg/kg)			**G**
N as Ammonium	**7.31**	**G**	**The extractable ammonium was higher than the reference sites.**
Extractable P	**146.0**	**G**	**The extractable phosphorus was higher than the reference sites.**
Extractable K	**126.0**	**G**	**The extractable potassium was similar to REF-03 and higher than REF-02.**
Extractable Fe	1876.6	Y	The extractable iron was higher than the reference sites.
Extractable Mn	18.5	Y	The extractable manganese was lower than the reference sites.
Fe:Mn	102.0	Y	The Fe:Mn ratio was higher than the reference sites.
Extractable Mg	**30.0**	**G**	**The extractable magnesium was similar to REF-02 but lower than REF-03.**

FB-02: Ranked Low to Not Impacted			G
The well drained soil at this site showed minimal impact from either fire or mining.			
Parent Material Texture			The silt loam glacio-fluvial parent material at this site was similar in texture to REF-03 and REF-02. All site comparisons were made to these two reference sites
Step A: Soil Development			G
The podzolic mineral soil horizons at this site were not eroded. The well developed LFH horizon at this site was typical of the freely drained relatively undisturbed modal soils of the region.			
Step B: Organic Matter (g/100g)			G
Total C	4.06	G	The total carbon was similar to REF-02 and lower than REF-03.
Total N	0.22	G	The total nitrogen was similar to both of the reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			G
Cation Exchange Capacity	**27.7**	**G**	**The CEC was similar to both of the reference sites.**
Calcium	3.83	G	The exchangeable calcium was higher than the reference sites.
Magnesium	0.81	G	The exchangeable magnesium was higher than the reference sites.
Ca:Mg Ratio	4.7	G	The Ca:Mg ratio was higher than the reference sites, perhaps indicative of minimal magnesium leaching.
Base saturation (%)	19.2	G	The base saturation was higher than REF-03 and higher than REF-02.
Step B: Fertility (mg/kg)			G
N as Ammonium	**36.2**	**G**	**The extractable ammonium was higher than the reference sites.**
Extractable P	**22.0**	**G**	**The extractable phosphorus was similar to the reference sites.**
Extractable K	**133.0**	**G**	**The extractable potassium was higher than the reference sites.**
Extractable Fe	1095.7	G	The extractable iron was similar to the reference sites.
Extractable Mn	228.8	Y	The extractable manganese was higher than the reference sites.
Fe:Mn	4.8	R	The Fe:Mn ratio was lower than the reference sites.
Extractable Mg	**67.0**	**G**	**The extractable magnesium was higher than REF-02 but lower than REF-03.**

FB-03: Ranked Moderately Impacted			Y
The Pozolic soil at this site was typical of the modal soils on the glacio-fluvial outwash within the Sudbury region. These soils generally have a relatively low moisture holding capacity. Although this site was not eroded, the amount of charcoal in the LFH horizon was indicative of a medium intensity fire in the recent past. Both soil exchange complex chemistry and site fertility indicated moderate impact.			
Parent Material Texture			The silt loam glacio-fluvial parent material at this site was similar in texture to REF-03 and REF-02 in terms of texture. All site comparisons were made to these two reference sites
Step A: Soil Development			**G**
The podzolic mineral soil horizons at this site were not eroded. However, the presence of charcoal in the moderately developed LFH indicates a severe burn or high intensity fire in the recent past.			
Step B: Organic Matter (g/100g)			**R**
Total C	2.74	R	The total carbon was lower than REF-02 and REF-03. Medium and large charcoal fragments are present in the LFH.
Total N	0.10	R	The total nitrogen was lower than both reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**28.4**	**G**	**The CEC was similar to both reference sites.**
Calcium	0.39	G	The exchangeable calcium was similar to REF-02 and lower than REF-03.
Magnesium	0.11	Y	The exchangeable magnesium was lower than both reference sites.
Ca:Mg Ratio	3.5	G	The Ca:Mg ratio was similar to REF-03 and higher than REF-02.
Base saturation (%)	2.4	Y	The base saturation was similar to REF-02 but lower than REF-03.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**1.49**	**G**	**The extractable ammonium was lower than both reference sites.**
Extractable P	**17.0**	**G**	**The extractable phosphorus was similar to both reference sites.**
Extractable K	**77.0**	**G**	**The extractable potassium was similar to REF-02 and lower than REF-03.**
Extractable Fe	676.4	Y	The extractable iron was lower than the reference sites.
Extractable Mn	4.8	Y	The extractable manganese was lower than the reference sites.
Fe:Mn	140.9	Y	The Fe:Mn ratio was higher than both reference sites.
Extractable Mg	**18.0**	**Y**	**The extractable magnesium was lower than the reference sites.**

FB-05: Ranked Moderately Impacted			**Y**
The Pozolic soil at this site was typical of the modal soils on the glacio-fluvial outwash within the Sudbury region. These soils generally have a relatively low moisture holding capacity. Although this site was not eroded, the charcoal fragments in the H layer indicate a historical fire of moderate intensity. Both soil exchange complex chemistry and site fertility indicate moderate impact.			
Parent Material Texture	The well drained sandy loam soil parent material at this site was coarser than all reference sites, but closest to REF-03 and REF-02 in terms of texture. All site comparisons were made to these two reference sites.		
Step A: Soil Development			**G**
The podzolic mineral soil horizons at this site were not eroded. The well developed LFH horizon at this site was typical of the very well drained relatively undisturbed modal soils of the region. The few fine charcoal fragments in the H layer did indicate past fire history.			
Step B: Organic Matter (g/100g)			**Y**
Total C	1.76	R	The total carbon was lower than both reference sites.
Total N	0.10	R	The total nitrogen was lower than both reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**11**	**R**	**The CEC was lower than both REF-02 and REF-03, however it is typical of sandy soils.**
Calcium	0.55	G	The exchangeable calcium was similar to REF-02 and lower than REF-03.
Magnesium	0.14	Y	The exchangeable magnesium was lower than both reference sites.
Ca:Mg Ratio	3.9	G	The Ca:Mg ratio was similar to REF-03 and higher than REF-02.
Base saturation (%)	7.5	G	The base saturation was lower than REF-03 and higher than REF-02.
Step B: Fertility (mg/kg)			**Y**
N as Ammonium	**0.2**	**Y**	**The extractable ammonium was lower than both reference sites.**
Extractable P	**23.0**	**G**	**The extractable phosphorus was similar to the reference sites.**
Extractable K	**60.0**	**Y**	**The extractable potassium was lower than both reference sites.**
Extractable Fe	1481.4	G	The extractable iron was higher than both reference sites.
Extractable Mn	58.7	G	The Manganese was higher than both reference sites.
Fe:Mn	25.2	G	The Fe:Mn ratio was lower than both reference sites.
Extractable Mg	**35.0**	**G**	**The extractable magnesium was higher than REF-02 and lower than REF-03.**

FB-06: Ranked Low to Not Impacted			**G**
The well drained soil at this site showed minimal impact from either fire or mining.			
Parent Material Texture			The silt loam glacio-fluvial parent material at this site was similar in texture to REF-03 and REF-02. All site comparisons were made to these two reference sites.
Step A: Soil Development			**G**
The podzolic mineral soil horizons at this site were not eroded. There were minor amounts of charcoal in the LF horizons.			
Step B: Organic Matter (g/100g)			**G**
Total C	7.73	G	The total carbon was higher than both reference sites.
Total N	0.35	G	The total nitrogen was higher than both reference sites.
Step B: Soil Exchange Complex Chemistry (cmol(+)/kg)			**Y**
Cation Exchange Capacity	**16**	**R**	**The CEC was lower than both reference sites, but is still typical of sandier forested soils.**
Calcium	1.4	G	The exchangeable calcium was higher than REF-02 and lower than REF-03.
Magnesium	0.33	G	The exchangeable magnesium was higher than REF-02 and lower than REF-03.
Ca:Mg Ratio	4.2	G	The Ca:Mg ratio was similar to REF-03 and higher than REF-02.
Base saturation (%)	12.7	G	The base saturation was similar to REF-03 and higher than REF-02.
Step B: Fertility (mg/kg)			**G**
N as Ammonium	**7.38**	**G**	**The extractable ammonium was higher than both reference sites.**
Extractable P	**20.0**	**G**	**The extractable phosphorus was similar to both reference sites.**
Extractable K	**73.0**	**G**	**The extractable potassium was lower than both reference sites.**
Extractable Fe	1478.2	G	The iron was higher than both reference sites, perhaps indicative of smelter fallout additions to the soil surface.
Extractable Mn	266.4	Y	The manganese was higher than both reference sites, perhaps indicative of smelter fallout additions to the soil surface.
Fe:Mn	5.5	Y	The Fe:Mn ratio was lower than both REF-02 and REF-03.
Extractable Mg	**24.0**	**Y**	**The extractable magnesium was similar to REF-02 and lower than REF-03.**

GD-9-2-6.0 UNCERTAINTY ANALYSIS

There is a high level of certainty with this LOE as the methodology provides relatively precise data. There is some inherent variability in the results, as natural soils tend to be very heterogeneous. As well, there was some uncertainty in developing the ranking ranges for the reference soil conditions due to the lack of comparative information in the literature. A summary of the issues and uncertainties related to the soil characterization LOE is provided below.

Issues:

- Minimal relevant regional soil-oriented research studies
- No regional soil survey data reports
- No regional routine soil chemical data
- No regional forest soil fertility data
- No regional soil analysis facility historically producing data (similar to the University of Guelph Soils Laboratory)

Uncertainties:

- pH of selected sites maintained within an order of magnitude
- Uniformity of soil forming materials
- Uniformity of site drainage class within individual transects
- Historical impact of erosion, logging and forest fire on sites

As a result, the SARA Group had to use reference sites as best fit models based on the parent material present at each site.

GD-9-2-7.0 CONCLUSIONS

Using the literature values and the reference site results, numerical ranges were established for various soil quality parameters to be indicative of typical northeastern Ontario forest soils (reference conditions). In addition, a range for each parameter was established to describe sites that could be considered as moderately or severely impacted. The test sites were compared to the reference sites and the parameter ranges, and an overall rank was given to each site. The majority of the test sites were ranked as "moderately impacted", indicating that at least some of the soil quality parameters measured at these sites might be limiting to plant growth. There were sites on both the Copper Cliff and Coniston transects that were ranked "severely impacted," indicating that the growing conditions at these sites were unlikely to be conducive to healthy plant growth. Two sites on the Falconbridge transect were ranked as low to not impacted, indicating that the growing conditions at these sites were comparable to the reference sites. The results of the ranking of the soil physical and chemical LOE will be evaluated along with the other three LOEs as part of the overall weight-of-evidence approach to the Sudbury ERA.

GD-9-2-8.0 REFERENCES

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