SUDBURY AREA RISK ASSESSMENT

APPENDIX GF-9: TOXICITY TESTING LOE RANKING REPORT

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GF-9-1.0 INTRODUCTION

The Ecological Risk Assessment (ERA) in Sudbury will evaluate the impact from airborne particulate emissions of the chemicals of concern (COC) to terrestrial ecological receptors. The soils in the Sudbury area contain a complex mixture of several metals that together will have a different toxicity potential than would be produced by a single metal. The COC for the Sudbury Risk Assessment are arsenic, copper, cadmium, cobalt, nickel, selenium and lead. The concentrations of these elements in Sudbury soils are generally highly positively correlated (MOE, 2004; CEM, 2004). The different smelters currently and/or historically emitted the various metals in different proportions, causing the absolute levels and ratios of the metals to differ within the study area. The risk assessment must take into account the combined toxicity of these metal mixtures, which differ spatially in the study area, and which cannot be accurately predicted using traditional toxicological models.

Objective #1 of the ERA is to evaluate the extent to which the chemicals of concern (COC) are preventing the recovery of regionally representative, self-sustaining terrestrial plant communities in the Sudbury region. To fulfill this objective, multiple lines of evidence (LOE) were investigated at 22 sites (18 test sites, three reference sites, and one historically limed and re-greened site) across the study area, the results of which were assessed to contribute to an overall weight-of-evidence approach to assess risk to ecological receptors.

For each LOE, each test site was ranked according to degree of impact based on a comparison to the reference sites. One of the lines of evidence was toxicity testing. The objective of the toxicity testing was to assess the toxicity of soils collected from different regions of Sudbury using a battery of single terrestrial species. This report describes the approach taken to analyze and assess the toxicity test results to reach an overall ranking for each site.

GF-9-2.0 RANKING APPROACH

The approach used to evaluate the toxicity testing results is summarized in Figure GF-9-2.1 and the steps are outlined in the following sections.

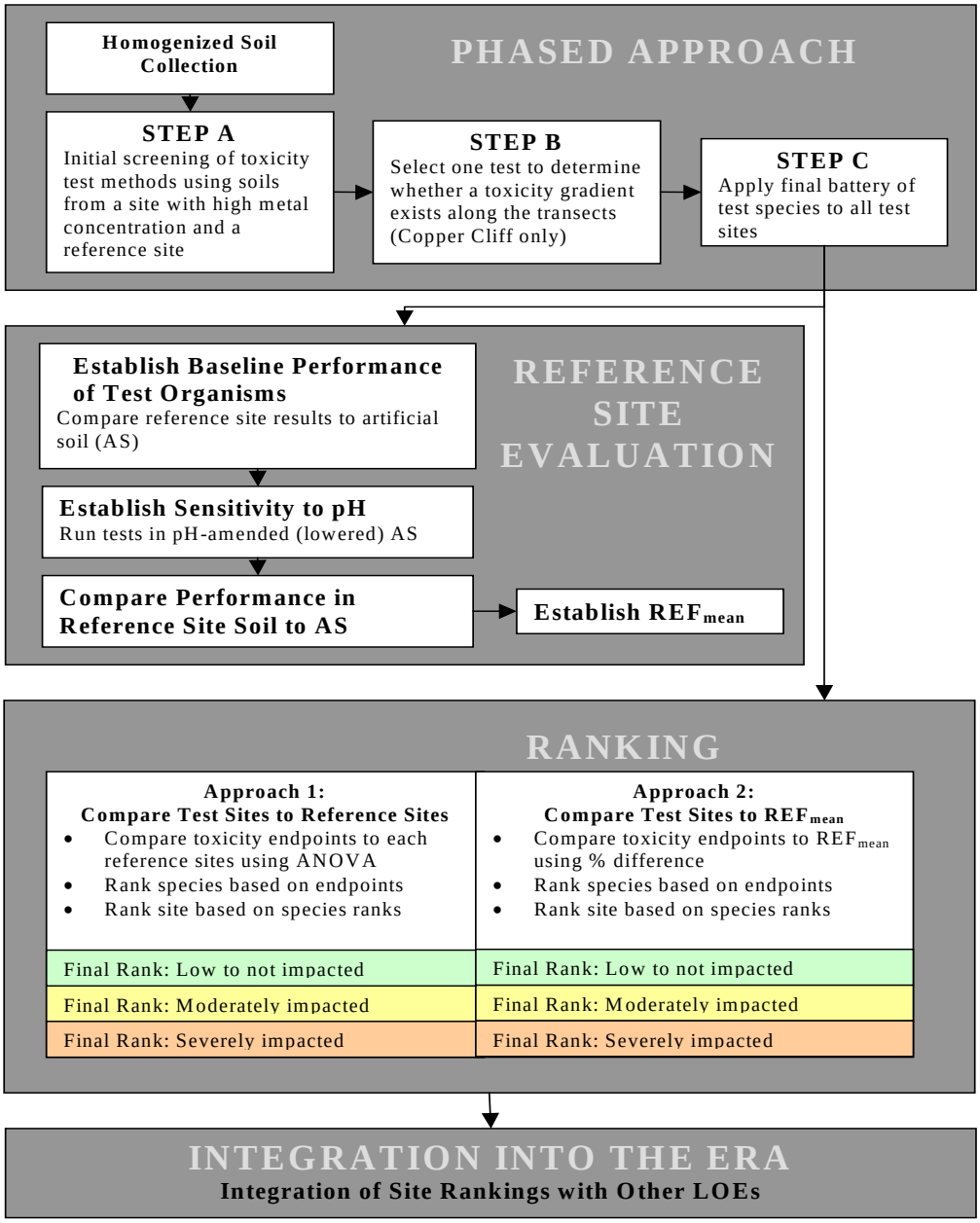

Figure GF-9-2-1 Overall Toxicity Testing Ranking Approach Used to Evaluate Toxicity of Soils from Test Sites

Toxicity Testing Approach

The general approach to the toxicity testing is shown in Figure GF-9-2.2. The methods, results and associated reports detailing the toxicity testing are outlined in Chapter 3.

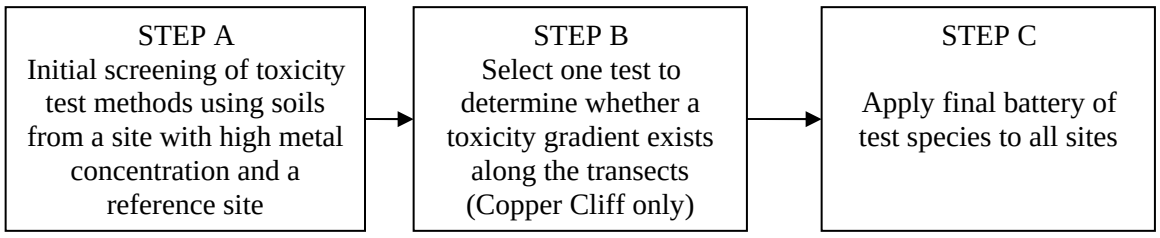

Figure GF-9-2-2 Stepwise Approach to Toxicity Testing of Sudbury Soils Developed for the ERA

This final battery of tests included various species, measurement endpoints and experimental conditions as summarized in Table GF-9-2.1. All species were tested in "natural" site soil (*i.e.*, or soil that was obtained directly from the study sites). The results of Step C above were used to evaluate and rank sites.

Table GF-9-2.1 Summary of Test Species, Conditions and Measured Endpoints Used to Evaluate and Rank Test Site Soils

Ecological Component	Test Species	Endpoint	Test Conditions
Trees	White Spruce	Root Length	Natural site soil
		Root Mass	
		Shoot Length	
		Shoot Mass	
Herbaceous (Monocot)	Northern Wheatgrass	Root Length	Natural site soil
		Root Mass	
		Shoot Length	
		Shoot Mass	
Herbaceous (Dicot)	Red Clover	Root Length	Natural site soil
		Root Mass	
		Shoot Length	
		Shoot Mass	
Herbaceous (Dicot)	Goldenrod	Root Length	Natural site soil
		Root Mass	
		Shoot Length	
		Shoot Mass	

Reference Site Evaluation

Various procedures were undertaken to evaluate the suitability of the toxicity tests using the reference site soil. This step was necessary since many of the standard laboratory test species and protocols are based on agricultural soils and their performance in low organic, low pH soils typical of the Sudbury region was unknown. The following comparisons were made:

- An evaluation of the performance of the organisms in artificial soil to provide baseline measurements;
- An evaluation of the sensitivity of the organisms to pH in artificial soil; and
- A comparison of the performance of the organisms in the reference soils, and in artificial soil (with the pH adjusted to a comparable level) to determine whether the reference soil was an appropriate test medium for the selected species.

The final test battery, which was selected using the approach described above, was applied to the reference sites. The results of these tests served as a point of comparison for the test site evaluation.

Test Site Evaluation

The final test battery was applied to the test sites, and the data were used to rank the test sites. Unlike the other LOE, two separate approaches were used in the toxicity LOE to independently rank the test sites:

- A comparison of the test site results to each of the three reference sites using ANOVA; and,
- A comparison of test site results to a mean of all three reference sites (REF_{mean}) using percent difference.

For each approach, individual species were ranked first, and then combined to give a site rank. The results from each approach were then compared. Where the two approaches produced identical results this became the overall rank for the test site, but where the two approaches produced different results, the site was given a split ranking.

Based on the results of the two approaches outlined in the sections below, each site was placed into one of three categories:

Green	Low to not impacted in comparison to the reference sites	The majority of the test species at these sites performed the same as or better than the test species at the reference sites.
Yellow	Moderately impacted in comparison to the reference sites	The majority of the test species at these sites performed at a level that was slightly lower than that observed at the reference sites. Some component of the soil appeared not to promote the measured endpoints (growth or reproduction) of the test species.
Red	Severely impacted in comparison to the reference sites	The majority of the test species at these sites performed at a level that was much lower than that observed at the reference sites. Some component of the soil appeared to seriously impact the measured endpoints (growth or reproduction) of the test species.

GF-9-3.0 SITE LOCATIONS

In total, 22 sites were located radiating from current and historical smelter sources in Copper Cliff (seven test sites), Falconbridge (five test sites), Coniston (six test sites) and one historically limed and re-greened site (CON-07*) which was located on the Coniston transect. Three reference sites were also chosen. The locations of the study sites are shown in Figure GF-9-3.1.

Various physical and chemical parameters were collected and analyzed at each site. The methods and results are presented under separate cover (Chapter 3 of the ERA). The test sites were chosen to have varying metal concentrations but a soil pH that was as similar as possible (range of 4.0 to 5.0). The orders of test sites from highest to lowest metal concentration are described below, where the actual COC concentrations are provided in Tables GF-9-3.1 to GF-9-3.3.

- CC-03, CC-01, CC-02, CC-04, CC-07, CC-06 and CC-08 for the Copper Cliff transect;
- FB-01, FB-02, FB-05, FB-06 and FB-03 for the Falconbridge transect; and
- CON-07*, CON-02, CON-05, CON-08, CON-03, CON-01 and CON-06 for the Coniston transect.

Table GF-9-3.1 Total (HNO_3 extracted) COC Concentrations (mg/kg) and pH from Soil Cores along the Coniston Transect

Site	pH ($CaCl_2$)	Arsenic	Cadmium	Cobalt	Copper	Lead	Nickel	Selenium
CON-01	3.44	9.5	0.28	5.51	76	28	77	0.85
CON-02	3.76	12.7	0.17	9.01	195	15.0	138	1.0
CON-03	3.61	28	0.24	11.5	191	35	112	0.92
CON-05	3.59	11.4	0.44	11.0	118	15.1	92.9	0.7
CON-06	4.03	2.1	0.12	9.4	48.7	4.6	70.2	0.3
CON-07[a]	6.45	7.2	0.15	10.2	240	11.0	255	1.1
CON-08	3.96	5.2	0.15	10.9	107	9.1	132	0.89

a CON-07 is the historically limed and re-greened site. The pH is consequently much higher than the other test sites. It was not considered in the final site rankings but is discussed in greater detail in Section 3.14.2 (Volume III, Chapter 3).

Table GF-9-3.2 Total (HNO_3 extracted) COC Concentrations (mg/kg) and pH from Soil Cores along the Falconbridge Transect

Site	pH ($CaCl_2$)	Arsenic	Cadmium	Cobalt	Copper	Lead	Nickel	Selenium
FB-01	3.21	117	0.99	23.3	655	162	422	5.6
FB-02	4.05	45	1.17	48.4	320	83	325	3.4
FB-03	3.64	10.9	0.28	4.84	87	28	78	1.1
FB-05	3.86	41	0.26	10.3	215	33	140	1.2
FB-06	3.48	26	0.61	11.7	200	61	179	1.7

Table GF-9-3.3 Total (HNO_3 extracted) COC Concentrations and pH from Soil Cores along the Copper Cliff Transect (mg/kg)

Site	pH ($CaCl_2$)	Arsenic	Cadmium	Cobalt	Copper	Lead	Nickel	Selenium
CC-01	3.81	46	1.26	26.7	960	70	700	6.2
CC-02	3.95	44	0.67	35.8	611	53	511	4.7
CC-03	3.81	72	0.61	41.5	1000	99.5	1100	10.5
CC-04	3.81	29	0.93	21.8	441	49	386	2.7
CC-06	3.85	15.5	0.43	9.9	144	17.2	103	1.5
CC-07	3.61	26	0.52	14.0	303	38	200	2.4
CC-08	3.62	9.6	0.27	7.81	97	29	77.5	1.4

In addition, there were three reference sites with soil pH comparable to the test sites and total copper and nickel concentrations that were found to be below those identified as 'background' concentrations in MOE Table F (MOE, 1996). These reference sites are identified as REF-02, REF-03 and REF-04 and the COC concentrations are provided in Table GF-9-3.4.

Table GF-9-3.4 Total (HNO_3 extracted) COC Concentrations (mg/kg) and pH from Soil Cores from the Reference Sites

Site	pH ($CaCl_2$)	Arsenic	Cadmium	Cobalt	Copper	Lead	Nickel	Selenium
REF-02	3.59	4.6	0.28	4.87	42	33	46	1.0
REF-03	4.14	2.66	0.23	11.5	18.7	14	40	0.48
REF-04	3.6	5.85	0.17	5.35	39.3	18.6	38.9	0.75

It is important to note that the metal concentrations of the test sites were not considered as part of the site ranking for the toxicity testing line of evidence. Although the laboratories undertaking the toxicity testing had to be aware of the site metal order so that cross contamination could not occur (all processing was undertaken from lowest metal to highest metal site), the evaluation of the performance of the test species in the various site soils was assessed independently of the metal concentration of the site.

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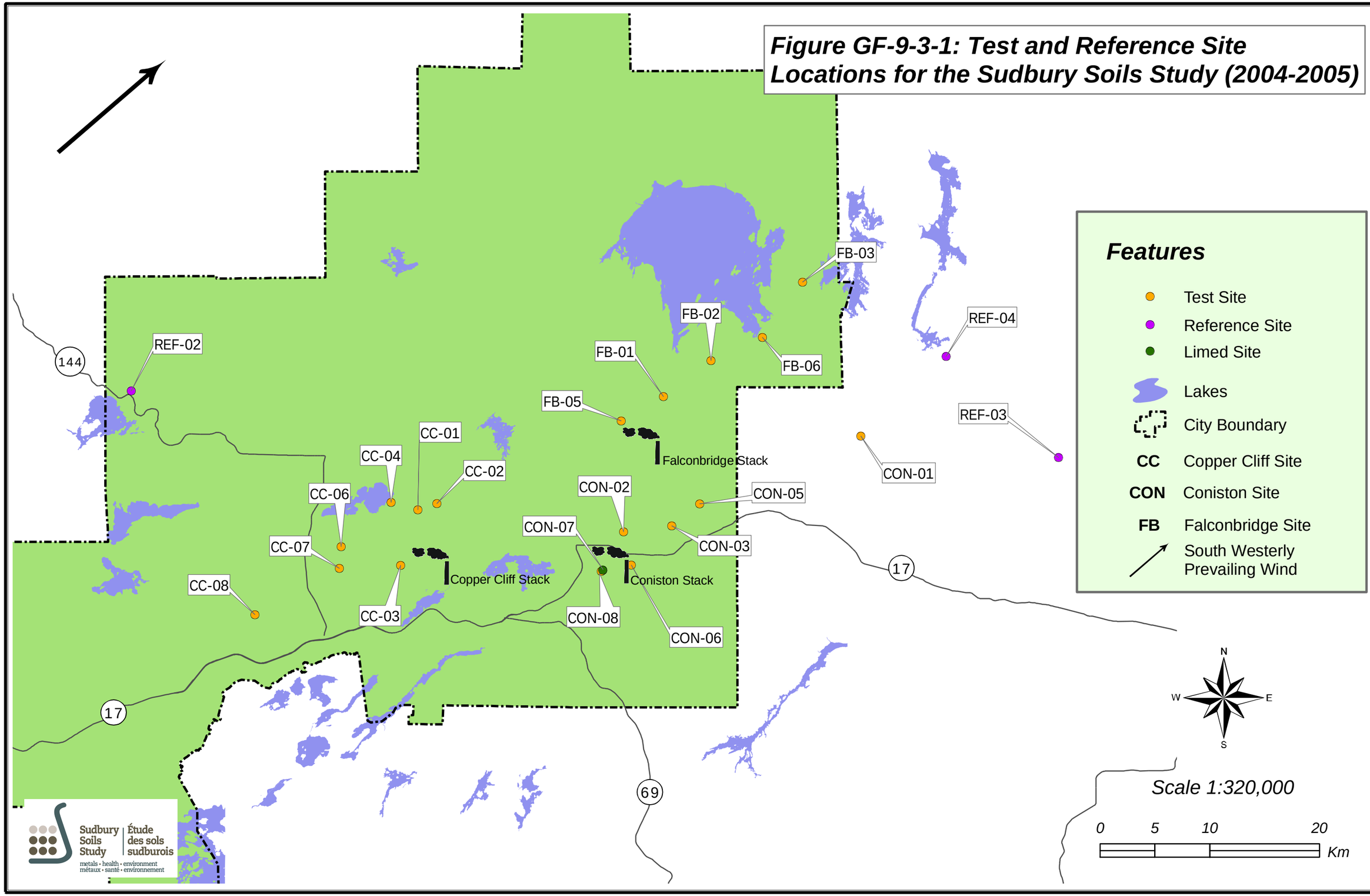
Figure GF-9-3-1: Test and Reference Site Locations for the Sudbury Soils Study (2004-2005)



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GF-9-4.0 REFERENCE SITE EVALUATION

Various procedures were undertaken to ensure that the results of the toxicity tests in the soil from the test sites could be reasonably compared to the performance of the tests in the reference soils. The following comparisons were made:

- An evaluation of the performance of the organisms in artificial soil to provide baseline measurements;
- An evaluation of the sensitivity of the organisms to pH in artificial soil; and,
- A comparison of the performance of the organisms in the reference soils to the artificial soil with a comparable pH to determine whether the reference soil was an appropriate test medium for the selected species.

One variable of great importance to the growth of plants and invertebrates was pH. The ambient pH of the Sudbury test soils was between 4.0 and 5.0. To remain representative of the region, the test and reference sites were deliberately chosen to have a natural pH that was similar to each other at about 5.0. A pH this low is potentially limiting for plant growth. Consequently, the pH of some of the site soil was amended to have a higher pH, and some toxicity tests with pH-sensitive species were run concurrently in natural and pH-amended soil.

In an effort to better understand the effects of low pH on plants and invertebrates, the initial test battery included tests with some species known to be pH-sensitive. These results are discussed in Appendix GF10. The issue of low ambient pH in Sudbury soils remains as a source of uncertainty in the toxicity testing LOE.

The artificial soil (AS) used by the laboratories as an internal control has a pH which is much greater than 5. Therefore, it was necessary to lower the pH of the AS for comparative purposes with site reference or test soils. Table GF-9-4.1 summarizes the pH values of the site soils and internal control soils. These comparisons are discussed in greater detail in the following sections.

Table GF-9-4.1 Range of pH Values in Artificial and Reference Site Soils

	AS_{high}	AS_{low}	Natural Reference Site Soil
pH range	6 - 7.5	5.2 ±0.2	4.09 – 4.88

Due to the wide diversity of species being tested in this study and the large number of sites, it was necessary to engage the services of three different laboratories. Therefore, additional efforts were made to ensure the consistency of approaches between the labs.

In the following sections, the reference site evaluation approach, rationale and results are described.

GF-9-4.1 Artificial Soil

The Environment Canada toxicity testing approach (Environment Canada publications, EPS 1/RM/43 – June 2004 and EPS 1/RM/45 – February 2005) recommends the use of a negative control soil referred to as "artificial soil," or AS. The AS offers a consistent, standardized substrate in which the performance of the organism can be measured to determine the health of the organisms and the validity of the tests being performed by individual laboratories.

The performance of all test species was evaluated in the AS. With every test in each laboratory, an internal laboratory control was conducted concurrently. Individual pH measurements were taken on all AS samples. The pH of the AS soil was generally between 6 and 7.5 (AS_{high}). These results are provided in the individual laboratory reports in Appendix GF of Volume III. In addition to the "normal" AS soil, AS with a lower pH (AS_{low}) consistent with the pH-amended reference site soils (5.2±0.2) was also used in tests conducted for northern wheatgrass and red clover. The performance of the test species in the AS soil was evaluated and compared to the performance at the reference sites.

GF-9-4.1.1 Establishing a Baseline of Organism Performance

Each test species was tested three times in the AS_{high} to establish the baseline performance of the test organisms. To document variation in the performance of the various organisms, the results from the three AS_{high} tests were averaged and the mean AS_{high} performance was calculated for each endpoint. The results of this analysis are presented in Appendix GF-9-A, Table GF-9-A1.

There were no established criteria for acceptable variability; however generally, for most species it was desirable to have a coefficient of variation of < 30 %. Not all endpoints or species met this criterion as a sample size of three does not adequately represent the natural distribution of variability that likely typifies responses.

This process revealed that the root and shoot lengths measured in northern wheatgrass, white spruce and goldenrod generally had an acceptable level of variation in the AS_{high}, although there was some variation with the weight endpoints in red clover and goldenrod. The test criteria for test validity were not met for the Coniston and Falconbridge transects. For example, the AS that was run concurrently with the Falconbridge soils did not meet its validity criteria.

GF-9-4.1.2 Establishing the Sensitivity of the Organism to pH

As an internal control for the health of the test species, the AS_{high} was used at the pH set out in the Environment Canada guidance document (Environment Canada, June 2004). This pH was much higher than the pH of the soil collected from the reference and test sites. To determine the sensitivity of the various test organisms to a pH that was lower than the EC guidance levels, additional toxicity tests in AS_{low} were conducted for northern wheatgrass, red clover and earthworms where the AS_{low} was adjusted to have a pH of approximately pH 5.2.

The performance of the organisms in AS_{high} and AS_{low} were compared to establish whether the altered pH affected their performance. The results of each scenario for the three test organisms were grouped together and the percent deviation was calculated. The results of this comparison are presented in Appendix GF-9-A, Table GF-9-A2, and revealed that, with the exception of earthworms, the organisms performed as well or better in the AS_{low} as in the AS_{high}.

The comparison between AS_{high} and AS_{low} revealed that the test organisms were able to perform at a lower pH.

GF-9-4.2 Comparison between the Performance of the Test Organisms in the Soil from the Reference Sites and in the Artificial Soil

A comparison was made between the pH-amended reference soil (amended to 5.2±0.2) and the AS_{low} to determine how the organisms would perform when pH was eliminated as a modifying factor. This comparison was necessary to establish the applicability of these toxicity tests in soil from the forested areas of northern Ontario because the majority of the testing protocols were developed for agricultural systems.

At similar pH, the test organisms consistently did not perform as well in the reference site soils as in the AS_{low}. The plant species (northern wheatgrass and red clover) had shoot and root lengths 30 to 40% shorter than in the AS_{low}, and individual root and shoot masses were 60 to 90% lower. The percent difference of each of the reference sites to a mean of the AS_{low} is presented in Appendix GF-9-A, Table GF-9-A3.

The results of this comparison demonstrated that, in the absence of pH as an influencing factor, the reference soils were limited by other variable(s). This finding did not affect the usefulness of the reference soils as a comparison to the test soils but did demonstrate that the chosen test species did not always perform well in Sudbury soils. In the absence of more regionally appropriate test species developed for forested regions, the battery of species selected for this study was considered to be the most appropriate option available at this time.

GF-9-4.3 Comparison between the Reference Sites

A statistical comparison of the performance of the test organisms in the natural soil from the three reference sites (REF-02, REF-03 and REF-04) was conducted. The comparisons were made using an analysis of variance (ANOVA) to determine if there was a significant ($p < 0.05$) difference among the measured endpoints from the various reference sites. If there was a significant difference among means, a Fisher's Protected Least Significant Difference (LSD) pairwise comparison test was conducted to identify which site endpoints significantly differed from each other ($p < 0.05$). The assumptions for the validity of the ANOVA and pairwise comparison test (*i.e.*, normality and homogeneity of variance) were tested. Normality was tested using a Shapiro-Wilk Normality test and a Levene's test was used to test for homogeneity of variance.

The results of the comparison between the reference sites are provided in Appendix GF-9-A, and are summarized below:

- Northern Wheatgrass and Red Clover: There was low to moderate variability of test performance between the reference sites.
- White Spruce: There was high variability in performance between the reference sites, with the exception of shoot length, which was similar at all sites.
- Goldenrod: There was high variability in performance between the reference sites. The performance at REF-03 was anomalously high.

These results show there was considerable variability in the ability of the test species to perform in the soil from the various reference sites. The following section discusses how this issue was addressed.

GF-9-4.4 Establishment of Reference Mean

Although there was variation between the performances of the test species in the soil from the three reference sites, no one reference site stood out as particularly poor; some reference sites were excellent for one species but not for another. For comparative purposes, a mean of the values for each endpoint for the three reference sites was established and was referred to as REF_{mean}. In the majority of cases, the REF_{mean} value provided a suitable baseline for comparison with the test sites and could be considered indicative of the average performance of the test species in soil from forested regions of the Sudbury area.

The results of the comparisons with REF_{mean} are provided in Appendix GF-9-A and are summarized below:

- Northern Wheatgrass: The value obtained for REF_{mean} can be considered indicative of the performance of northern wheatgrass in soil from forested regions of the Sudbury area.
- Red Clover: The value obtained for REF_{mean} is higher than some of the reference sites but can be considered indicative of the average performance of red clover in soil from forested regions of the Sudbury area.
- White Spruce: The value obtained for REF_{mean} can be considered indicative of the average performance of white spruce in soil from forested regions of the Sudbury area.

- Goldenrod: The performance at REF-03 was anomalously high and influenced the value obtained for REF_{mean}. As a result, REF_{mean} may be higher than the average performance of goldenrod in soil from forested regions of the Sudbury area.

Test site data were compared to REF_{mean} (Approach 2, see GF-9-5.0). To further address the variability in performance at the reference sites, test site data were also compared to data from individual reference sites (Approach 1, see GF-9-5.0).

GF-9-5.0 TEST SITE EVALUATION

An overall ranking—severely impacted (red), moderately impacted (yellow), or low to not impacted (green)—was determined for each site (18 test sites and one historically limed and re-greened site) based on the performance of the battery of test species in natural soil using two separate approaches. The methods used in the two approaches are discussed in the following sections and are summarized as follows:

Approach 1: Compare toxicity test endpoint results using test site soil to each of the three reference sites.
Approach 2: Compare toxicity test endpoint results using test site soil to the REF_{mean}.

The two approaches were combined to give the overall ranking for the site. This is summarized in Figure GF-9-5.1 discussed in more detail in the following sections.

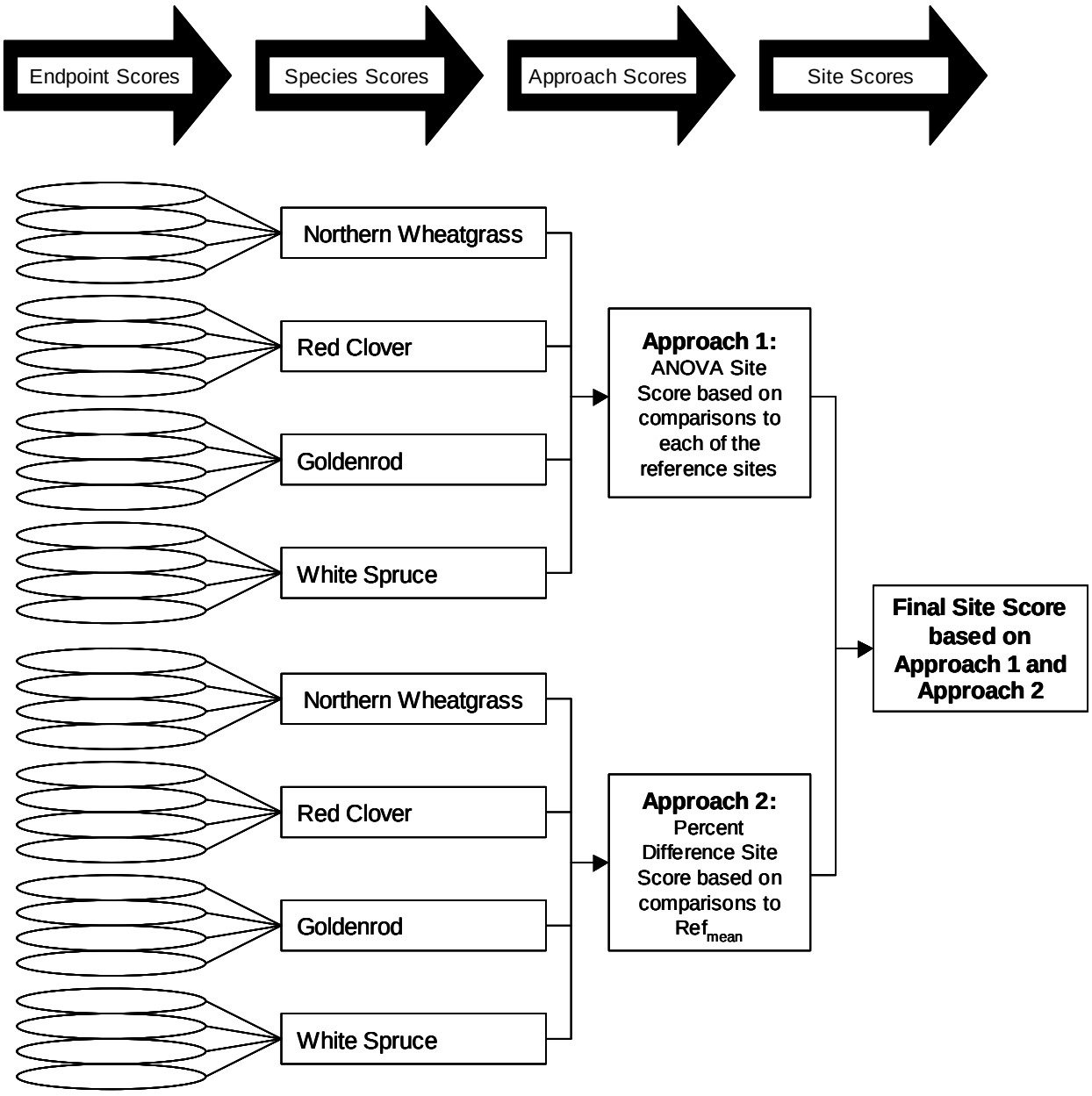

Figure GF-9-5-1 Conceptual Diagram Summarizing the Ranking Approach for Soil Toxicity Data

GF-9-5.1 Approach 1: Comparison between Test Sites and Reference Sites

The toxicity data from each of the test sites were statistically compared to the results from each of the three reference soils (REF-02, REF-03 and REF-04). The toxicity test endpoints measured in the various studies are summarized in Table GF-9-2.1.

The toxicity data for the test site soils were compared to the three reference soils using an analysis of variance (ANOVA) to determine if there was a significant ($p < 0.05$) difference among treatment means. If there was a significant difference among means, a Fisher's Protected Least Significant Difference (LSD) pairwise comparison test was conducted to identify which means significantly differed from each other ($p < 0.05$). The assumptions for the validity of the ANOVA and pairwise comparison test (*i.e.*, normality and homogeneity of variance) were tested. Normality was tested using a Shapiro-Wilk Normality test and a Levene's test was used to test for homogeneity of variance.

Using the results of the ANOVA analysis, the toxicity test results from each site were ranked using the steps presented in Figure GF-9-5-2 and described in Section GF-9-4.3. The results of the comparisons between the reference sites and each test site are provided in Appendix GF-9-B.

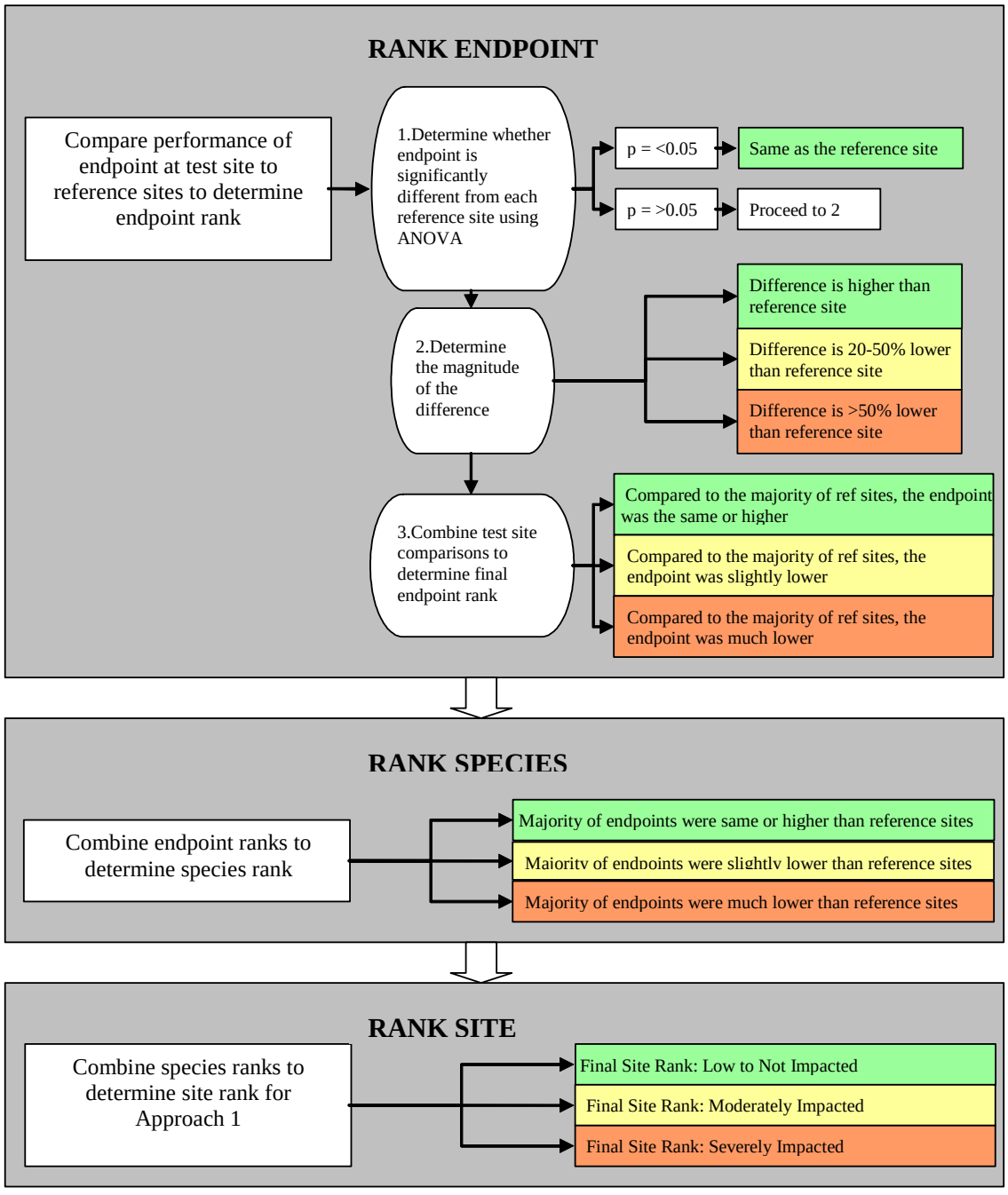

Figure GF-9-5-2 Overview of Approach 1: Species and Site Ranking Schemes based on Soil Toxicity Data

GF-9-5.2 Approach 2: Comparison between Test Sites and REF_{mean}

The toxicity results from each of the test sites were compared to the mean of the toxicity endpoint from the three reference soils (REF_{mean}).

The data from REF_{mean} and each test site were compared by calculating the percent difference between the test sites and the REF_{mean} value.

Percent difference was calculated using the following formula:

$$\text{Percent Difference} = \left(\frac{\text{result1} - \text{result2}}{(\text{result1} + \text{result2})/2} \right) \times 100$$

Percent difference using the above formula was the approach used in the Port Colborne risk assessment study (JWEL 2005). The comparison of the test sites to REF_{mean} was ranked using the steps presented in Figure GF-9-5-3 and described in Section GF-9-4.3. The results of the comparison between each test site and REF_{mean} are provided in Appendix GF-9-C.

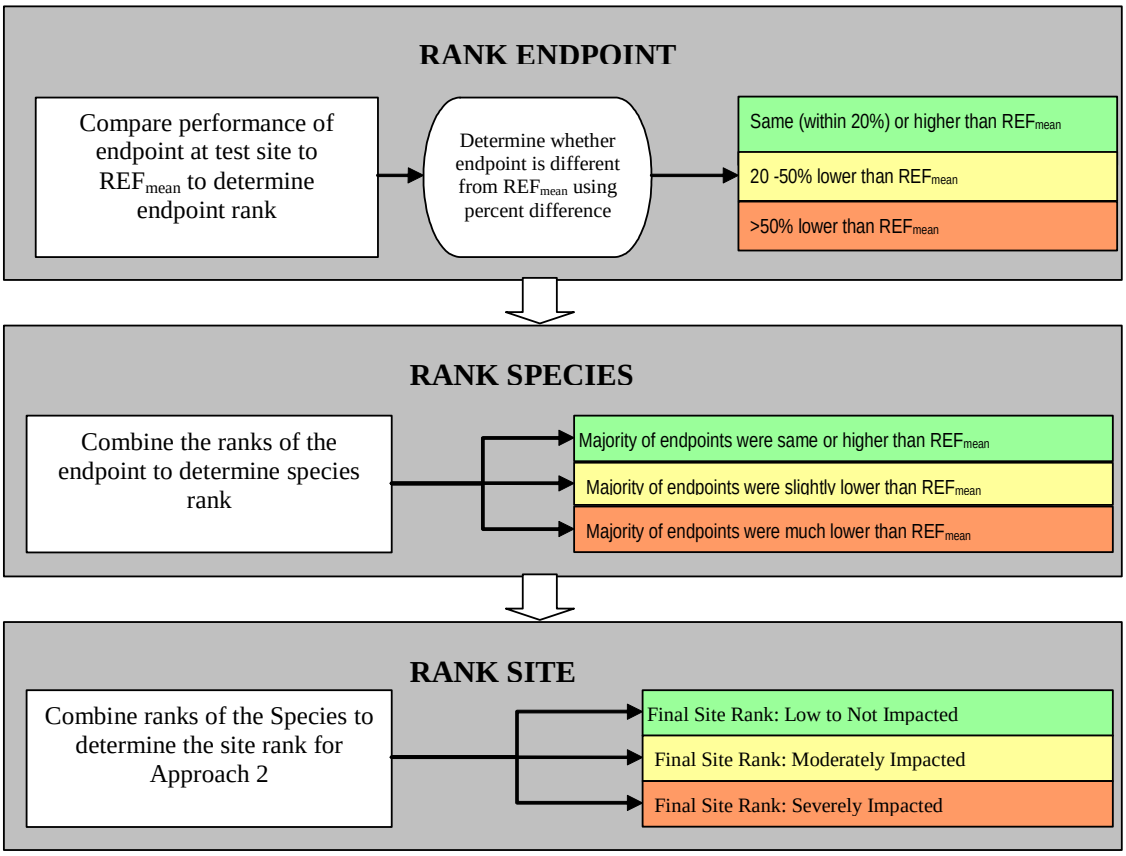

Figure GF-9-5-3 Overview of Approach 2: Species and Site Ranking Schemes based on a Comparison with REF_{mean}

GF-9-5.3 Ranking and Weighting for Both Approaches

For both approaches, the ranking for each site was conducted in three steps, which are explained in further detail below:

1) Each endpoint was ranked based on the amount by which it differed from the reference sites (Approach 1) or from REF_{mean} (Approach 2).
2) Each species was ranked based on its endpoints, according to the ranking table below (Table GF-9-5.1)
3) Each site was ranked based on the rank of the test species, for each approach.

GF-9-5.3.1 Step One: Ranking Endpoints

Approach 1: Endpoint Ranking in Relation to Separate Reference Sites

To determine the ranking for each endpoint in relation to the reference sites, the following steps were undertaken:

1. Determine whether the endpoint at the test site is different from the endpoint at the reference site using an analysis of variance (ANOVA). The p-value determined whether or not the test site was significantly different from the reference sites as follows:

P-value	Preliminary Endpoint Rank
< 0.05	Endpoint was significantly different from reference site
> 0.05	Endpoint was not significantly different from reference site

   Endpoints that were not significantly different from the reference sites were ranked green. All endpoints that were significantly different were considered in the next step.

2. Determine the magnitude of the difference between the endpoint at the test site and reference site. In some instances the endpoint was significantly different than the reference site but the value was higher. If this was the case, then the endpoint was ranked green. The endpoints that were significantly different *and* lower than the reference sites were assigned a rank of yellow or red based on the magnitude of this difference. A yellow ranking was given to the endpoint if the value was less than 50% different and a red was given if the value was greater than 50% different. This 50% increment was chosen as the marker because it was similar to an LD_{50}—the point at which a lethal dose of a chemical causes 50% mortality of the test species. Each endpoint was ranked according to the following table:

Preliminary Endpoint Rank	Comment
Green	No significant difference or value higher than reference site
Yellow	Significant difference, value less than 50% lower than reference site
Red	Significant difference, value more than 50% lower than reference site

3. Determine an overall endpoint rank based on combined ranks from the three reference sites. The overall endpoint rank was based on a majority rule (according to GF-9-5.1 below), where the colour in the greatest number of cells was used as the final rank. Where other factors needed to be considered, best professional judgement was applied to obtain a conservative ranking. The overall endpoint rankings were coded as follows:

Endpoint Rank	Comment
Green	Test performance no different or better than reference sites
Yellow	Test performance slightly lower than reference sites
Red	Test performance much lower than reference sites

Approach 2: Endpoint Ranking in Relation to REF_{mean}

To determine the ranking for each endpoint in relation to REF_{mean}, the following steps were followed:

1. Determine percent difference between REF_{mean} and each of the endpoints for each species. To do this, the percent difference between the test sites and REF_{mean} was calculated and the ranking was determined as follows:

Endpoint Rank	Comment
Green	Test site endpoint is no more than 20% lower than REF_{mean}
Yellow	Test site endpoint is between 20.1% and 50% lower than REF_{mean}
Red	Test site endpoint is more than 50% lower than REF_{mean}

The ranking was based on the following rationale:

All samples that were within 20%, the typical limit for determining similarity for quality assurance/quality control applications, of the REF_{mean} value were considered the same as $REF_{mean.}$ These endpoints were given a green ranking, denoting that low to no impact in the measured parameters had occurred.

All samples that were more than 50% lower than the REF_{mean} were considered severely impacted. Fifty percent is a typical designation for determining percent difference and is comparable to the LD_{50}, a common toxicological benchmark. Although in this instance mortality was not the measurement in question, 50% difference was deemed acceptable for the more sensitive endpoints measured during the toxicity tests. These endpoints were ranked red denoting that the measured parameters had been severely impacted.

All samples that were between 20 and 50% lower than the REF_{mean} were ranked yellow, denoting a moderate impact.

GF-9-5.3.2 Step 2: Species Ranking

For every site, each test species was ranked based on its performance for the majority of endpoints. A rank of green represented a performance similar to or better than the reference sites, yellow represented a performance slightly lower than the reference sites and red represented a performance much lower than the reference sites.

GF-9-5.3.3 Step 3: Ranking Sites Based on Approach

The ranking key in Table GF-9-5.1 was used to determine the approach-specific ranking for the site, based on the ranks of the test species. The same ranking approach was utilized for the determination of the endpoint ranking (where, for instance, root length, shoot length, root weight and shoot weight would be parameters 1, 2, 3 and 4) and the test species ranking (where, for instance, northern wheatgrass, red clover, white spruce and goldenrod would be parameters 1, 2, 3 and 4). An overall rank of green represents a performance similar to or better than the reference sites, yellow represents a performance slightly lower than the reference sites and red represents a performance much lower than the reference sites.

Table GF-9-5.1 Sample Ranking Table and Possible Outcomes for the Overall Performance of Test Species

Parameter 1[a]	Parameter 2	Parameter 3	Parameter 4	Overall Rank
[b]Green	Green	Green	Green	**Green**
Green	Green	Green	Yellow	**Green**
Green	Green	Yellow	Yellow	**Yellow**
Green	Yellow	Yellow	Yellow	**Yellow**
Yellow	Yellow	Yellow	Yellow	**Yellow**
Yellow	Yellow	Yellow	Red	**Yellow**
Yellow	Yellow	Red	Red	**Red**
Yellow	Red	Red	Red	**Red**
Red	Red	Red	Red	**Red**
Red	Red	Red	Green	**Red**
Red	Red	Green	Green	**Red**
Red	Green	Green	Green	**Yellow**
Green	Green	Yellow	Red	**Yellow**
Green	Yellow	Yellow	Red	**Yellow**
Green	Yellow	Red	Red	**Red**

[a]where "parameter" represents individual endpoint for endpoint ranking, species for species ranking, approach for approach ranking
[b]where each row represents a species, a site…

For example, if applied to endpoints, the ranking legend might be:

Northern Wheatgrass: Shoot Weight	Northern Wheatgrass: Shoot Length	Northern Wheatgrass: Root Length	Northern Wheatgrass: Root Weight	Overall Rank for Northern Wheatgrass
The shoot weight is between 20 and 50% lower than REF_{mean}/reference sites	The shoot length is between 20 and 50% lower than REF_{mean}/reference sites	The root length is more than 50% less than REF_{mean}/reference sites	The root weight is more than 50% less than REF_{mean}/reference sites	At this site NWG can be considered severely impacted with respect to the performance of NWG at the reference sites. The roots of this species are more affected than the shoots

If applied to test species, the ranking legend might look like this:

Northern Wheatgrass	Red Clover	White Spruce	Goldenrod	Overall Rank
Severely Impacted	Low to No Impact	Moderately Impacted	Severely Impacted	Two species are severely impacted (NWG and goldenrod), one is moderately impacted (white spruce) and one does not appear to be impacted (red clover) in comparison to the reference sites/REF_{mean}. Overall, this site is ranked severely impacted**.**

GF-9-5.3.4 Step 4: Combining the Two Approaches to Produce Overall LOE Ranking

The two approaches were weighted equally in the overall ranking for the site. If the approaches provided identical rankings for the test site, then no further evaluation was required to determine the overall LOE ranking. If the two methods were not in agreement, the site was given a split ranking (such as red/yellow or yellow/green) to illustrate the separate rankings.

The overall LOE rankings were coded as follows:

Rank	Comment
Green	Low to Not Impacted
Yellow	Moderately Impacted
Red	Severely Impacted

The results of the combination of approaches can be found in Appendix GF-9-D.

GF-9-6.1 SUMMARY OF RESULTS

Following the integration and evaluation of all the data collected during the toxicity testing LOE, overall LOE rankings were given to each of the 18 test sites. CON-07, the historically limed and re-greened site was ranked at the individual LOE level for comparison purposes, but was not given a final site ranking. These rankings were based on the two separate evaluation methods: a comparison of each test site to all three reference sites; and, a comparison to the mean value from all reference sites (REF_{mean}).

The final toxicity testing ranking for each site is presented in Table GF-9-6.1 and in Figure GF-9-6-1.

Table GF-9-6.1 Summary of Overall Toxicity Test Rankings Based on Two Separate Evaluation Methods

Site	Approach 1	Approach 2	Overall LOE Ranking
CC-01	R	R	R
CC-02	R	R	R
CC-03	R	R	R
CC-04	R	R	R
CC-06	Y	R	Y / R
CC-07	R	R	R
CC-08	Y	Y	Y
CON-01	Y	Y	Y
CON-02	R	R	R
CON-03	Y	R	Y / R
CON-05	Y	R	Y / R
CON-06	R	R	R
CON-07*	Y	Y	Y
CON-08	R	R	R
FB-01	R	R	R
FB-02	Y	R	Y / R
FB-03	Y	R	Y / R
FB-05	G	Y	G / Y
FB-06	G	G	G

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

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Figure GF-9-6-1: Toxicity Testing LOE Overall Site Ranking

Features

Toxicity Ranking

- Severely Impacted
- Moderately Impacted
- Slightly Impacted to No Impact
- Test Site
- Limed Site
- Lakes
- City Boundary
- **CC** Copper Cliff
- **CON** Coniston
- **FB** Falconbridge
- South Westerly Prevailing Wind

FB-03
FB-02
FB-06
FB-05
FB-01
Falconbridge Stack
CON-01
CON-05
CON-02
CON-07
CON-03
CON-06
CON-08
CC-04
CC-02
CC-06
CC-01
CC-08
CC-07
CC-03
Copper Cliff Stack
Coniston Stack
144
17
69

Sudbury Soils Study | Étude des sols sudburois
metals • health • environment
métaux • santé • environnement

N
W
E
S

Scale 1:300,000

0 5 10 20 *Km*

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Detailed results for the toxicity tests are provided in Appendices GF-9-A to GF-9-D.

The toxicity test results established that the soil from the reference sites provided an adequate baseline with which to compare the test site soils. Although the performance of the organisms in the reference site soils was lower than in the artificial soil, for the most part, the test battery species were able to thrive and survive in the reference soil. For some of the test species, pH emerged as a definite contributor to toxicity, and the performance of the organisms could not be evaluated in the natural soil. Appendix GF10 elaborates on the effect of pH-amendment in relation to the toxicity testing results.

There was some fluctuation in the performance of the organisms at the various reference sites but there was no one reference site that emerged as substandard when compared to the others. As a result, an additional factor was created (REF_{mean}) which moderated the extreme values and provided an additional test site comparison.

For the most part, the two evaluation methods produced the same ranking for each test site. Where the two methods were not in agreement, a split ranking was allocated to the site so that no one evaluation method was given precedence over the other.

The evaluations revealed the following:

1) **Copper Cliff:** The majority of the test sites were ranked "severely impacted."
2) **Coniston:** The site with the highest metal concentration (CON-07) was the historically limed site. This site cannot be compared directly to the remaining test sites because the pH was much higher, but it was evaluated for discussion purposes (Section 3.14.2 of Chapter 3, Volume III). CON-07 was ranked "moderately impacted." The remaining sites on the Coniston transect were ranked either "severely impacted", or between "severely impacted" and "moderately impacted." The exception to this was site CON-01, which was ranked "moderately impacted" by both ranking methods.
3) **Falconbridge:** The site with the highest metal concentrations, FB-01, was ranked "severely impacted." FB-02 and FB03 were given a split rank between "severely impacted" and "moderately impacted". The remaining two sites were given "low to moderately impacted" ranks.

GF-9-6.0 UNCERTAINTIES AND LIMITATIONS

GF-9-6.1 Soil Storage

The storage time for field soils in the laboratory is stipulated by Environment Canada (EC) in the two test protocols and the duration was exceeded prior to the soils being shipped to Stantec from Ottawa. Upon receipt at the Stantec laboratory, the soils were tested within an acceptable time frame. As the soil samples were stored in Ottawa in cold storage, it is unlikely that the physico-chemical characteristics of the soil would have changed substantially over the duration of the holding time. The metal levels are unlikely to change but potentially there could be changes to bioavailability. Given that the contamination is historical, changes are likely to be relatively small.

GF-9-6.2 pH Sensitivity

For the specific species selected for testing, northern wheatgrass is tolerant of relatively low pH (e.g., 3.8 to 5.0), and red clover is less tolerant. The comparative growth metrics reflected the difference in sensitivities to soil pH. White spruce is also relatively tolerant of low soil pH. Toxicity test results in pH-amended soil are presented in Appendix GF10.

GF-9-6.3 Bioavailability/Bioaccessibility

To date there is no standardized method of determining the bioavailable fraction of metals in soil. Our approach was to use a variety of extraction methods and calculate statistically which best correlated to the toxicological endpoints. Section 3.15 in Chapter 3 determined that there was not one particular methodology that best fit the data across the board, instead different methods seemed to better predict for the different endpoints and the different metals. The extraction precision depended largely on soil type, plant type, metal or metals involved. As a result the “plant available” fractions were not always better correlated to plant toxicity than the total metals in soil. This is often the case for complex metal mixtures like the ones that typify the Sudbury region, which is further confounded by the natural heterogeneity among site soils within and among transects.

GF-9-6.4 Test Battery Limitations

The use of surrogate species is also a source of uncertainty. No test battery is truly representative of the diversity of species and communities present in the natural environment or truly representative of the range of sensitivities that could potentially exist.

Northern wheatgrass was selected as a test species. It is a native temperate C3 grass that grows from Alaska east and south across Canada, as well as further south throughout western U.S.A. and Mexico. According to Dore and McNeill (1980) northern wheatgrass (by its earlier scientific name *Agropyron dasystachyum*) is widespread throughout the Prairie Provinces but has been reported in Ontario in the Thunder Bay District only. However, the same reference describes a subspecies *of A. dasystachyum – A. dasystachyum* var. *psammophilum*, also referred to as *Elymus lanceolatus* (the new taxonomic classification of northern wheatgrass), as Great Lakes wheatgrass and is found along the shores of Lakes Michigan and Huron including Manitoulin Island. Therefore, although northern wheatgrass might not be native to the Sudbury region it is found within parts of northern and midwestern Ontario.

Although northern wheatgrass might not be native to the Sudbury region, it is an appropriate species to use because:

- It is a cool-season species;
- It is the only non-agricultural, native Canadian species recommended in the Environment Canada method;
- Past toxicity assessments with this species have demonstrated its sensitivity to soil contaminants, including metals (ESG, 2000); and,
- It has been used previously in toxicity assessments of soils from the Sudbury region and exhibited sensitivity to these soils contaminated with metal mixtures relative to a site-specific reference soil (ESG, 2002; Feisthauer et al., 2006).

Goldenrod was not a standardized test species and as such, the amount of natural variability was unknown at the time of analysis. More recent research has provided more insight into the matter, and has established that high variability in goldenrod is common but was unknown at the time of the SARA testing (Mary Moody, personal communication).

GF-9-6.5 Extrapolation

Uncertainties are also inherent in extrapolating toxicity data generated by single-species laboratory toxicity tests to field systems. Single-species toxicity tests usually over-estimate the toxicity of the contaminant(s) under investigation. Single-species toxicity tests evaluate direct effects of a contaminant on an organism without integrating secondary effects that result from interactions among species and trophic groups, and also only partially integrate the behaviour (e.g., bioavailability) of the contaminant within the system.

Some of the myriad of factors that modify the toxicity of metals in soils that are not addressed in single-species toxicity tests include the:

- Plasticity of sensitivity within a species;
- Range of sensitivities among species, genera, families, classes, phyla and kingdoms, although this is partially addressed by testing a battery of species;
- Influence and variability of site-specific growing conditions including temperature, moisture, photoperiods, disease, grazing pressure/predation etc.;
- Evolved tolerance of local species to metal contamination and/or low pH; and,
- Significant variability of the physicochemical characteristics of contaminated soils within the Sudbury region that influence metal bioavailability and hence toxicity.

Single-species toxicity tests are only one line of evidence in a weight of evidence approach. The value of single-species toxicity testing data is greatly enhanced when it can be evaluated in conjunction with other lines of evidence that do measure secondary toxic effects and integrate the site-specific effects of growing conditions and contaminant behaviour (e.g., the ecological LOE).

GF-9-7.0 SUMMARY AND CONCLUSION

Extensive toxicity testing was undertaken to validate the performance of standard toxicity test species in Sudbury soils. In addition, the influence of soil pH on soil toxicity was examined to establish the sensitivity of test organisms to low pH. Further evaluations of this information together with the other LOE collected must be undertaken to determine if there are other causative factors that might contribute to the toxicity of the soils at the test sites other than metals. However, the evidence from these toxicity tests suggests that an association exists between the concentration of metals in the soil and impairment of the ability of plants to grow in this soil.

GF-9-8.0 REFERENCES

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APPENDIX GF-9-A

REFERENCE SITE EVALUATION

Table GF-9.A1 Summary of Variation in Mean Endpoint Values for Test Species in Artificial Soil (pH_{high}, n=3)

Test Species	Endpoint	Mean	Standard Deviation	Variation in SD Compared to Mean
Northern Wheatgrass	Shoot Length (mm)	145.64	13.81	9.5 %
	Root Length (mm)	204.17	27.74	13.6 %
	Indv Shoot Weight (mg)	14.74	2.62	17.8 %
	Indv Root Weight (mg)	6.92	2.05	29.6 %
Red Clover	Shoot Length (mm)	28.91	8.74	30.2 %
	Root Length (mm)	74.49	48.42	65.0 %
	Indv Shoot Weight (mg)	6.01	0.64	10.6 %
	Indv Root Weight (mg)	2.08	1.52	73.0 %
White Spruce	Shoot Length (mm)	31.26	1.52	4.9 %
	Root Length (mm)	114.42	14.09	12.3 %
	Indv Shoot Weight (mg)	12.50	0.98	7.8 %
	Indv Root Weight (mg)	5.26	0.71	13.5 %
Goldenrod	Shoot Length (mm)	22.22	6.13	27.6 %
	Root Length (mm)	182.61	27.57	15.1 %
	Indv Shoot Weight (mg)	9.06	4.23	46.7 %
	Indv Root Weight (mg)	14.57	4.86	33.4%

The mean endpoint values for test species grown in artificial soil (AS) are presented in Table GF-9.A1. The mean endpoint values for northern wheatgrass and red clover in artificial soil (AS_{high}) and pH-amended artificial soil (AS_{low}) are shown below in Table GF-9.A2.

Table GF-9.A2 Comparison (Percent Difference) Between Mean Endpoint Values for Test Species in Artificial Soil pH_{high} and pH_{low} n=3

Test Organism	Endpoint	Mean AS_{High}	Mean AS_{Low}	Percent Difference
Northern Wheatgrass	Shoot Length (mm)	145.64	158.66	8.6%
	Root Length (mm)	204.17	191.48	-6.4%
	Indv Shoot Weight (mg)	14.74	16.98	14.1%
	Indv Root Weight (mg)	6.92	7.33	5.7%
Red Clover	Shoot Length (mm)	28.91	45.41	44.4%
	Root Length (mm)	74.49	148.81	66.6%
	Indv Shoot Weight (mg)	6.01	8.10	29.6%
	Indv Root Weight (mg)	2.08	4.11	65.4%

Table GF-9.A3 Comparison (Percent Difference) between Mean Endpoint Values for Test Species in AS_{low} and Reference Site Soil

Test Organism	Endpoint	REF-02	REF-03	REF-04
Northern Wheatgrass	Shoot Length (mm)	-25.4%	-38.4%	-48.1%
	Root Length (mm)	-30.7%	-37.8%	-31.0%
	Indv Shoot Weight (mg)	-90.7%	-90.2%	-108.2%
	Indv Root Weight (mg)	-69.4%	-56.1%	-72.9%
Red Clover	Shoot Length (mm)	-39.9%	-52.4%	-52.3%
	Root Length (mm)	-25.4%	-64.9%	-30.4%
	Indv Shoot Weight (mg)	-33.8%	-88.5%	-57.6%
	Indv Root Weight (mg)	-30.1%	-98.8%	-60.0%

Table GF-9.A3 compares mean endpoint values from all 3 reference site locations with the endpoint values in AS_{low}.

Comparison of Species Performance in Reference Site Soils: Data and Analysis

To assess the variability between each of the reference sites (REF-02, REF-03 and REF-04) a statistical comparison of the performance of the test organisms from the three reference soils was conducted in the natural and pH-amended site soils. The comparisons were made using an analysis of variance (ANOVA) to determine if there was a significant ($p < 0.05$) difference among treatment means. If there was a significant difference among means, a Fisher's Protected Least Significant Difference (LSD) pairwise comparison test was conducted to identify which means significantly differed from each other ($p < 0.05$). The assumptions for the validity of the ANOVA and pairwise comparison test (*i.e.*, normality and homogeneity of variance) were tested. Normality was tested using a Shapiro-Wilk Normality test and a Levene's test was used to test for homogeneity of variance.

To assess the variability of the reference sites to REF_{mean} the percent difference between the REF_{mean} and each of the reference sites was determined and designations of high variability (>50% different); moderate variability (20%–50% different) or low variability (<20% different) were given.

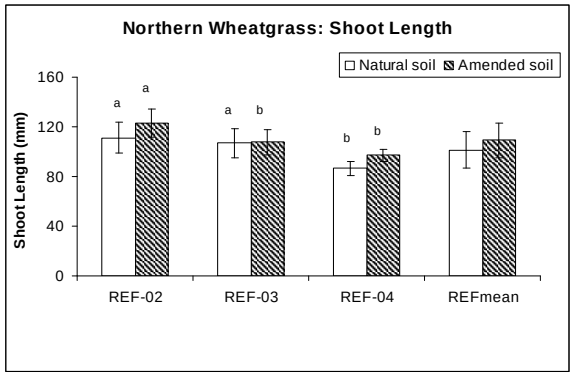
In the following sections the results and an overall evaluation of the performance of each test species at the reference sites is discussed. The value obtained for REF_{mean} is provided in the tables and graphs for comparative purposes.

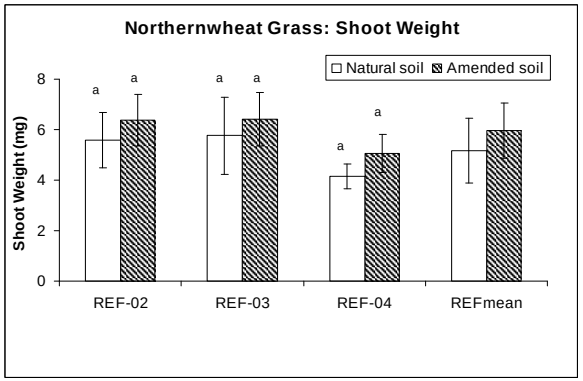
Northern Wheatgrass

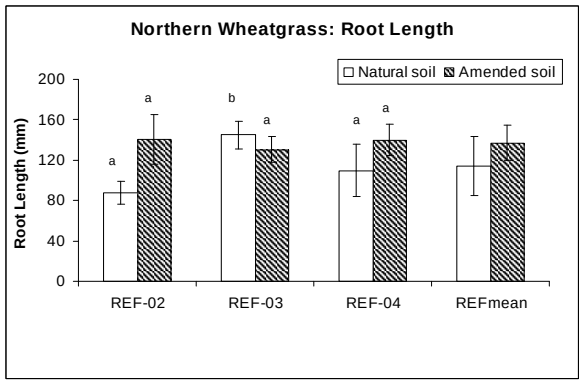
Northern wheatgrass was tested in natural soil and soil that was amended to have a pH of approximately 5.2±0.2. Shoot length, shoot weight, root length and root weight were assessed. The mean performance of the various endpoints tested at the three reference sites and REF_{mean} are presented in Table GF-9.A4 and Figure GF-9-A1. Overall there was low to moderate variability in the performance of northern wheatgrass at the various reference sites. The value obtained for REF_{mean} can be considered indicative of the performance of northern wheatgrass in soil from forested regions of the Sudbury area.

Table GF-9.A4 Comparison Between the Performance of Northern Wheatgrass Endpoints at the Reference Sites and REF_{mean} in Natural and pH-amended Soil

		REF-02	REF-03	REF-04	REF_{mean}	REF_{sd}	REF_{cv}	Comments
Natural Soil	Shoot Length (mm)	111.1	106.9	86.5	101.5	13.2	13%	Moderate variability between the performances of the reference sites.
	Root Length (mm)	87.8	145.0	109.6	114.1	28.9	25%	Moderate variability between the performances of the reference sites.
	Indv Shoot Weight (mg)	5.6	5.8	4.2	5.2	0.9	17%	Moderate variability between the performances of the reference sites.
	Indv Root Weight (mg)	2.3	4.2	2.5	3.0	1.0	35%	High variability between the performances of the reference sites.
pH-amended Soil	Shoot Length (mm)	122.9	107.6	97.2	109.2	12.9	12%	Low variability between the performances of the reference sites.
	Root Length (mm)	140.5	130.7	140.0	137.1	5.5	4%	Low variability between the performances of the reference sites..
	Indv Shoot Weight (mg)	6.4	6.4	5.1	6.0	0.8	13%	Moderate variability between the performances of the reference sites.
	Indv Root Weight (mg)	3.6	4.1	3.4	3.7	0.4	10%	Low variability between the performances of the reference sites.
% change attributable to pH, relative to Natural soil	Shoot Length (mm)	11%	1%	12%	8%			High variability between the performances of the reference sites attributable to pH.
	Root Length (mm)	60%	-10%	28%	20%			Moderate variability between the performances of the reference sites attributable to pH.
	Indv Shoot Weight (mg)	14%	10%	21%	15%			Low variability between the performances of the reference sites attributable to pH.
	Indv Root Weight (mg)	57%	-2%	36%	23%			High variability between the performances of the reference sites attributable to pH.







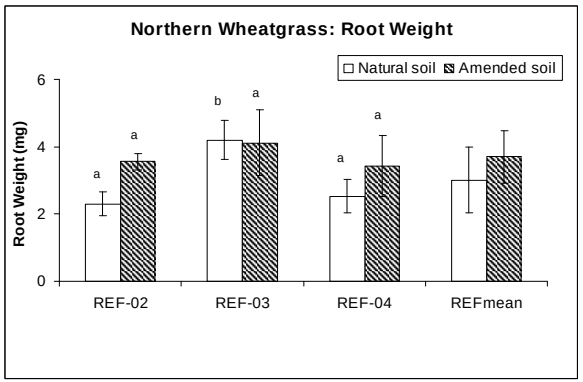


Figure GF-9-A1 Comparison Between Endpoints Tested in Northern Wheatgrass

Red Clover

Red Clover was tested in natural soil and soil that was amended to have a pH of approximately 5.2±0.2. Shoot length, shoot weight, root length and root weight were assessed. The mean performance of the various endpoints tested at the three reference sites and REF_{mean} are presented in Table GF-9.A5 and Figure GF-9-A2. Overall there was moderate to high variability between the performance of red clover at the various reference sites. The value obtained for REF_{mean} is higher than some of the reference sites but can be considered indicative of the average performance of red clover in soil from forested regions of the Sudbury area.

Table GF-9.A5 Comparison Between the Performance of Red Clover Endpoints at the Reference Sites and REF_{mean} in Natural and pH-amended Soil

		REF-02	REF-03	REF-04	REF_{mean}	REF_{sd}	REF_{cv}	Comments
Natural Soil	Shoot Length (mm)	19.7	24.7	13.9	19.4	5.4	28%	Moderate variability between the performances of the reference sites.
	Root Length (mm)	64.0	104.5	22.9	63.8	40.8	64%	High variability between the performances of the reference sites.
	Indv Shoot Weight (mg)	4.2	2.0	3.3	3.2	1.1	35%	High variability between the performances of the reference sites.
	Indv Root Weight (mg)	1.1	0.4	0.7	0.8	0.4	44%	High variability between the performances of the reference sites.
pH-amended Soil	Shoot Length (mm)	30.3	26.5	26.6	27.8	0.1	0%	Low variability between the performances of the reference sites.
	Root Length (mm)	115.3	75.9	109.6	100.3	21.3	21%	Moderate variability between the performances of the reference sites.
	Indv Shoot Weight (mg)	5.8	3.1	4.5	4.5	1.4	30%	Moderate variability between the performances of the reference sites.
	Indv Root Weight (mg)	3.0	1.4	2.2	2.2	0.8	36%	High degree of variability between the performances of the reference sites.
% change attributable to pH, relative to Natural soil	Shoot Length (mm)	35%	7%	91%	43%			High variability between the performances of the reference sites attributable to pH.
	Root Length (mm)	80%	-27%	379%	57%			High variability between the performances of the reference sites attributable to pH.
	Indv Shoot Weight (mg)	38%	55%	36%	41%			Moderate variability between the performances of the reference sites attributable to pH.
	Indv Root Weight (mg)	173%	250%	214%	175%			Moderate variability between the performances of the reference sites attributable to pH.

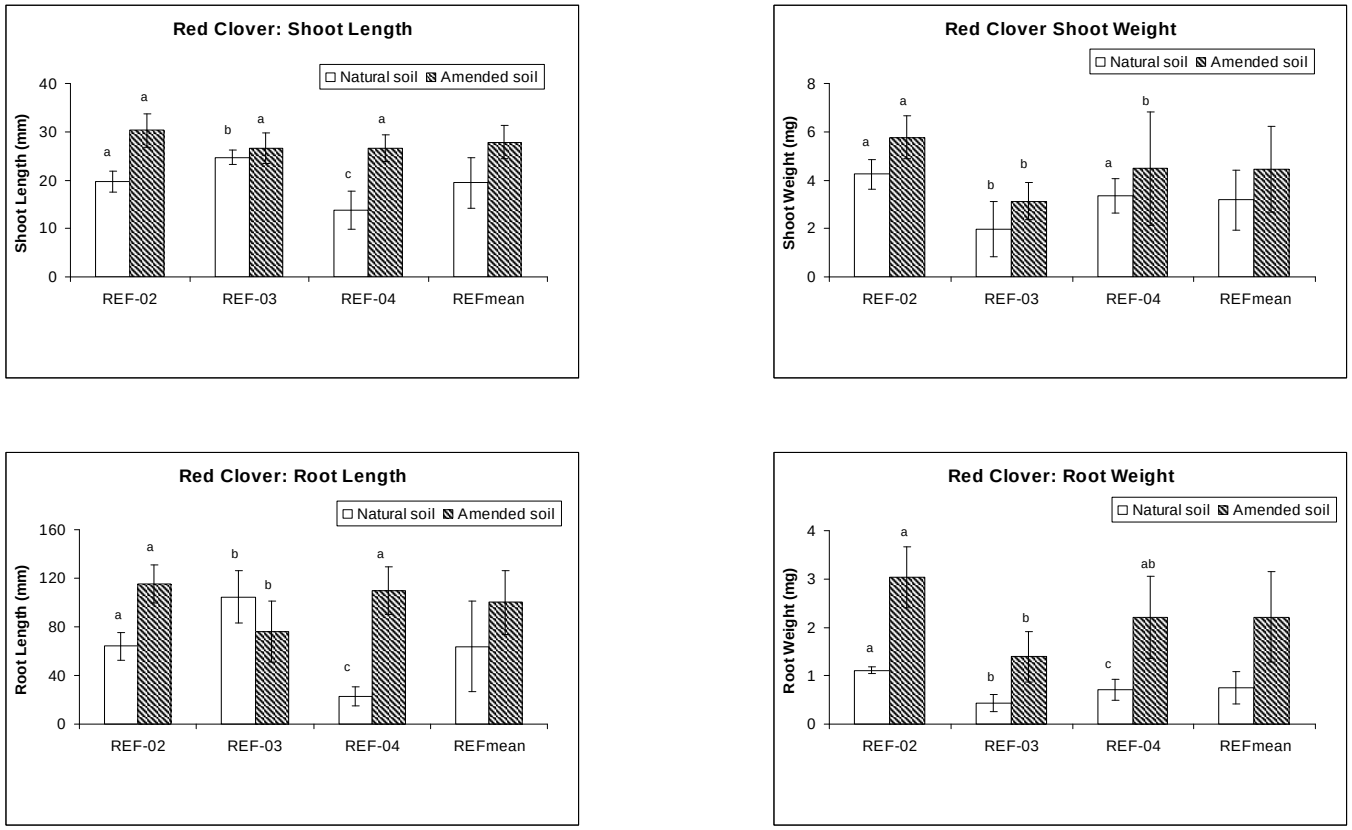


Figure GF-9-A2 Comparison Between Endpoints Tested in Red Clover

White Spruce

White Spruce was tested in natural soil only. Shoot length, shoot weight, root length and root weight were assessed. The mean performance of the various endpoints tested at the three reference sites and REF_{mean} are presented in Table GF-9.A6 and Figure GF-9-A3. Overall there was high variability between the performance of white spruce at the various reference sites with the exception of shoot length, which was similar at all sites. The value obtained for REF_{mean} can be considered indicative of the average performance of white spruce in soil from forested regions of the Sudbury area.

Table GF-9.A6 The Performance of White Spruce Endpoints at the Reference Sites and REF_{mean} in Natural Soil

		REF-02	REF-03	REF-04	REF_{mean}	REF_{sd}	REF_{cv}	Comments
Natural Soil	Shoot Length (mm)	28.1	29.8	30.4	29.4	1.2	4%	Low variability between the performances of the reference sites.
	Root Length (mm)	46.5	70.6	92.0	69.7	22.8	33%	High degree of variability between the performances of the reference sites.
	Indv Shoot Weight (mg)	4.4	5.9	10.1	6.8	3.0	43%	High degree of variability between the performances of the reference sites.
	Indv Root Weight (mg)	0.7	1.5	3.4	1.9	1.4	73%	High variability (<100%) between the performances of the reference sites.

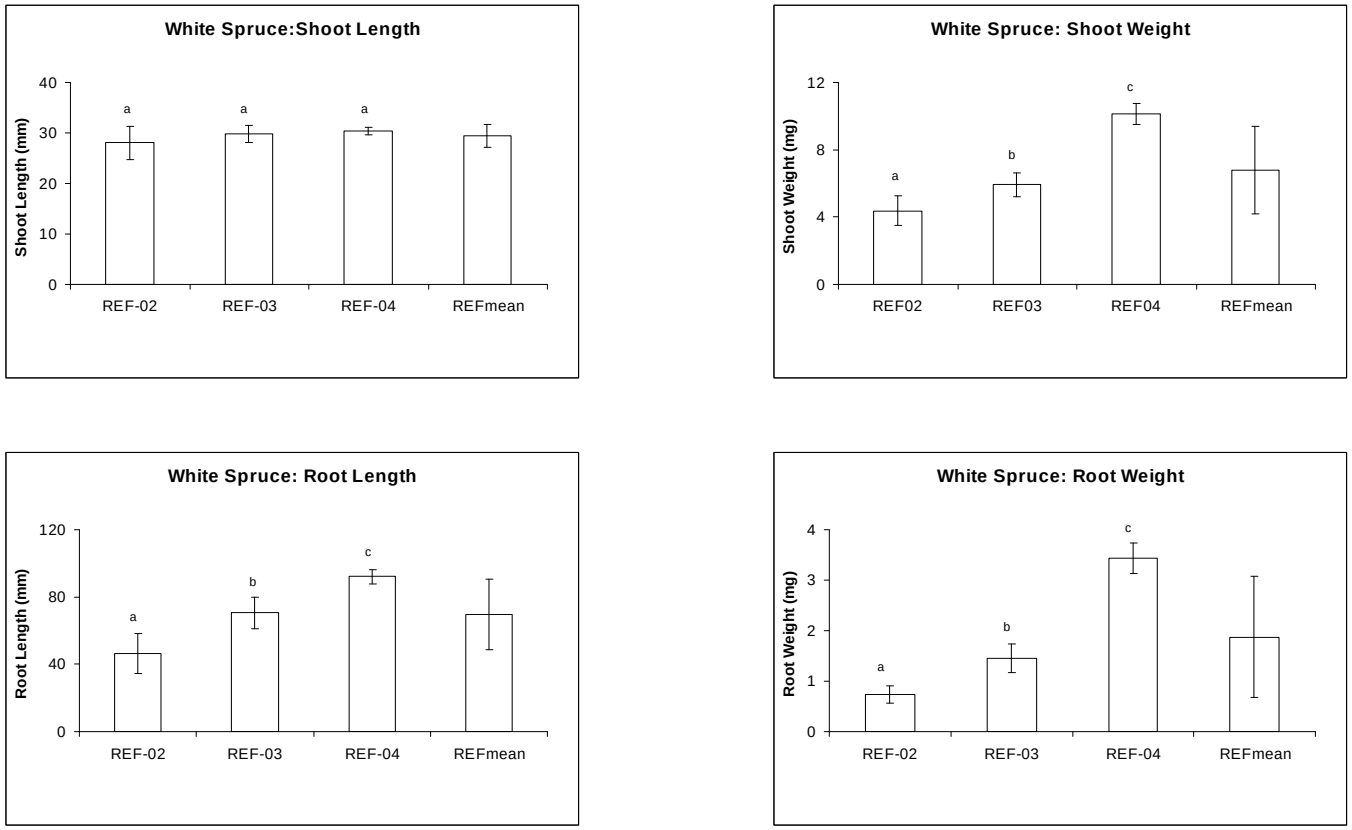


Figure GF-9-A3 Comparison Between Endpoints Tested in White Spruce in Natural Soil

Goldenrod

Goldenrod was tested in natural soil only. Shoot length, shoot weight, root length and root weight were assessed. The mean performance of the various endpoints tested at the three reference sites and REF_{mean} are presented in Table GF-9.A7 and Figure GF-9-A4. Overall there was high variability between the performance of goldenrod at the various reference sites. The performance at REF-03 was anomalously high and influenced the value obtained for REF_{mean}. As a result REF_{mean} may be higher than the average performance of goldenrod in soil from forested regions of the Sudbury area.

Table GF-9.A7 The Performance of Goldenrod Endpoints at the Reference Sites and Ref_{mean} in Natural Soil

		REF-02	**REF-03**	**REF-04**	**REF_{mean}**	**REF_{sd}**	**REF_{cv}**	**Comments**
Natural Soil	Shoot Length (mm)	5.7	56.6	6.1	22.8	29.3	128%	High variability (<100%) between the performances of the reference sites.
	Root Length (mm)	20.0	142.0	24.6	62.2	69.1	111%	High variability (<100%) between the performances of the reference sites.
	Indv Shoot Weight (mg)	0.3	21.7	0.7	7.6	12.2	161%	High variability (<100%) between the performances of the reference sites.
	Indv Root Weight (mg)	0.2	4.9	0.6	1.9	2.6	137%	High variability (<100%) between the performances of the reference sites.

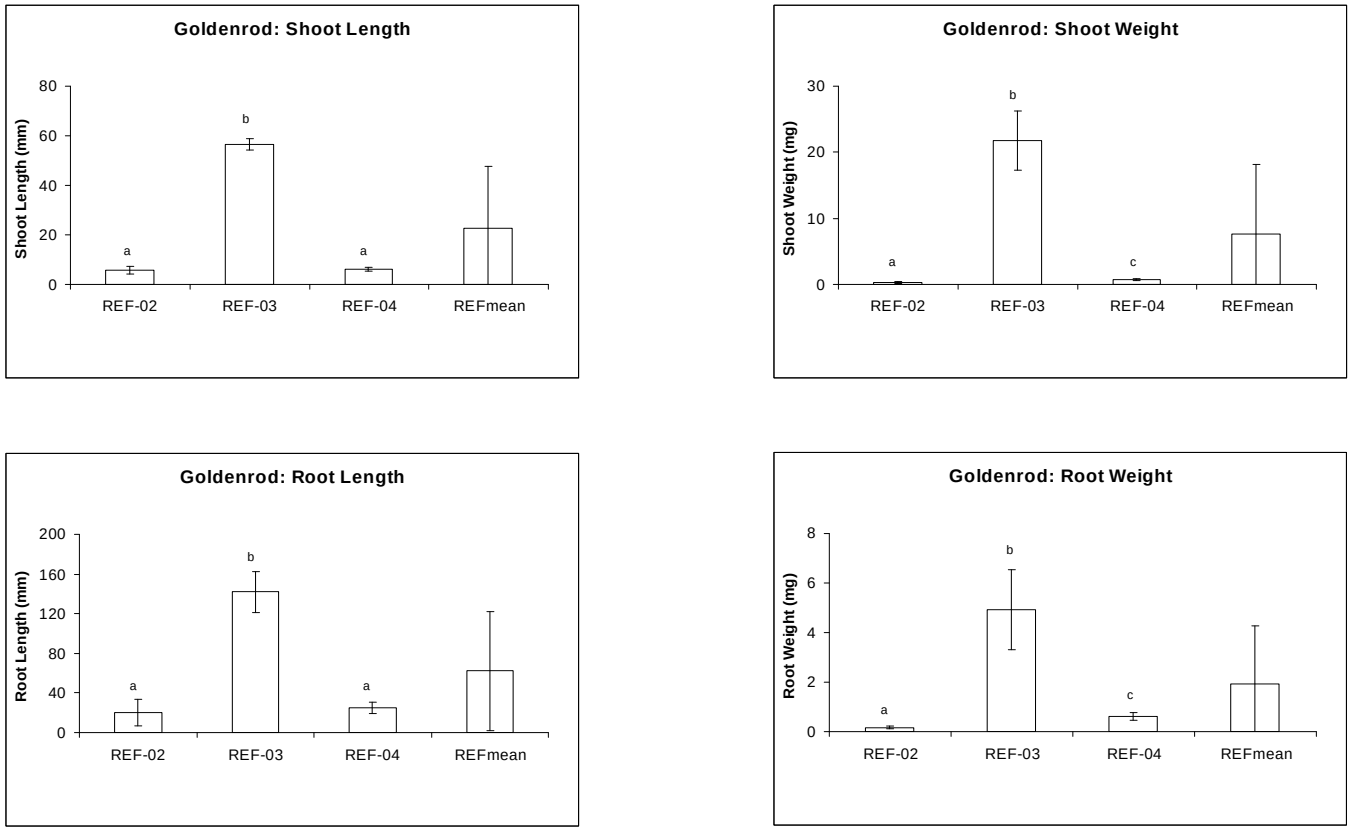


Figure GF-9-A4 Comparison Between Endpoints Tested in Goldenrod in Natural Soil

APPENDIX GF-9-B

APPROACH 1: COMPARISONS BETWEEN THE TEST SITES AND THE REFERENCE SITES

Summary of Reference Site Data - Natural Soil

Reference Sites

Endpoint		REF-02	REF-03	REF-04	REF_{mean}
Northern Wheatgrass					
Natural	Shoot Length	111.1mm	106.9mm	86.5 mm	101.5mm
	Root Length	87.8 mm	145.0mm	109.6mm	114.1mm
	Shoot Weight	5.6 mg	5.8 mg	4.2 mg	5.2 mg
	Root Weight	2.3 mg	4.2 mg	2.5 mg	3 mg
Red Clover					
Natural	Shoot Length	19.7 mm	24.7 mm	13.9 mm	19.4 mm
	Root Length	64.0 mm	104.5mm	22.9 mm	63.8 mm
	Shoot Weight	4.2 mg	2.0 mg	3.3 mg	3.2 mg
	Root Weight	1.1 mg	0.4 mg	0.7 mg	0.8 mg
White Spruce					
Natural	Shoot Length	28.1 mm	29.8 mm	30.4 mm	29.4 mm
	Root Length	46.5 mm	70.6 mm	92.0 mm	69.7 mm
	Shoot Weight	4.4 mg	5.9 mg	10.1 mg	6.8 mg
	Root Weight	0.7 mg	1.5 mg	3.4 mg	1.9 mg
Goldenrod					
Natural	Shoot Length	5.7 mm	56.6 mm	6.1 mm	22.8 mm
	Root Length	20.0 mm	142.0mm	24.6 mm	62.2 mm
	Shoot Weight	0.3 mg	21.7 mg	0.7 mg	7.6 mg
	Root Weight	0.2 mg	4.9 mg	0.6 mg	1.9 mg

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-01: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	82.1 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	22.1 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.9 mg	Y	Y	Y	The shoot weight was significantly lower than the reference sites.	Y
	Root Weight	0.8 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	18.9 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 and REF-04.	G
	Root Length	10 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.7 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.4 mg	R	Y	Y	The root weight was significantly lower than the reference sites.	Y
White Spruce							
Natural	Shoot Length	24.5 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	10.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.8 mg	Y	R	R	The shoot weight was significantly lower than the reference sites.	R
	Root Weight	0.5 mg	Y	R	R	The root weight was significantly lower than the reference sites.	R
Goldenrod							
Natural	Shoot Length	2 mm	R	R	R	The shoot length was significantly lower than the reference sites.	R
	Root Length	1 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.3 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.2 mg	G	R	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	R

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-02: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	83.7 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	23.2 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.4 mg	Y	Y	G	The shoot weight was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Weight	0.9 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	18.2 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	13.1 mm	R	R	Y	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.5 mg	Y	G	G	The shoot weight was significantly different from REF-02, but not significantly different from REF-03 or REF-04.	G
	Root Weight	0.3 mg	R	G	R	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	R
White Spruce							
Natural	Shoot Length	28 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	35.5 mm	Y	Y	R	The root length was significantly lower than the reference sites.	Y
	Shoot Weight	4.8 mg	G	G	R	The shoot weight was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	Y
	Root Weight	1 mg	G	Y	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
Goldenrod							
Natural	Shoot Length	2.7 mm	R	R	R	The shoot length was significantly lower than the reference sites.	R
	Root Length	2.4 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.4 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.2 mg	G	R	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	R

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-03: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	66.5 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
Natural	Root Length	7.5 mm	R	R	R	The root length was significantly lower than the reference sites.	R
Natural	Shoot Weight	2.9 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
Natural	Root Weight	0.2 mg	G	Y	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
Red Clover							
Natural	Shoot Length	13.2 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
Natural	Root Length	8.5 mm	R	R	R	The root length was significantly lower than the reference sites.	R
Natural	Shoot Weight	4.1 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
Natural	Root Weight	0.5 mg	R	G	G	The root weight was significantly lower than REF-02, but not significantly different from REF-03 or REF-04.	Y
White Spruce							
Natural	Shoot Length	18.6 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
Natural	Root Length	4.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
Natural	Shoot Weight	2.3 mg	Y	R	R	The shoot weight was significantly lower than the reference sites.	R
Natural	Root Weight	0.3 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Goldenrod							
Natural	Shoot Length	2.5 mm	R	R	R	The shoot length was significantly lower than the reference sites.	R
Natural	Root Length	–	R	R	R	Golden rod seedlings emerged, but did not grow roots or survive.	R
Natural	Shoot Weight	0.3 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
Natural	Root Weight	–	R	R	R	Golden rod seedlings emerged, but did not grow roots or survive.	R

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-04: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	76.8 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	22.7 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.9 mg	Y	Y	Y	The shoot weight was significantly lower than the reference sites.	Y
	Root Weight	0.9 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	18.2 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	11.7 mm	R	R	Y	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.7 mg	Y	G	G	The shoot weight was significantly lower than REF-02, but not significantly different from REF-03 or REF-04.	G
	Root Weight	0.2 mg	R	Y	R	The root weight was significantly lower than the reference sites.	R
White Spruce							
Natural	Shoot Length	29.5 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	32.6 mm	Y	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	8.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.3 mg	G	G	Y	The root weight was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	G
Goldenrod							
Natural	Shoot Length	2.4 mm	R	R	R	The shoot length was significantly lower than the reference sites.	R
	Root Length	3.1 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.3 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.2 mg	G	R	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	R

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-06: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	98.5 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	73.5 mm	G	Y	Y	The root length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Shoot Weight	4.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.0 mg	G	R	Y	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
Red Clover							
Natural	Shoot Length	22 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	20.1 mm	R	R	G	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	R
	Shoot Weight	3.9 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.6 mg	Y	G	G	The root weight was significantly lower than REF-02, but not significantly different from REF-03 and REF-04.	G
White Spruce							
Natural	Shoot Length	25 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	12.4 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.1 mg	Y	Y	R	The shoot weight was significantly lower than the reference sites.	Y
	Root Weight	0.4 mg	Y	R	R	The root weight was significantly lower than the reference sites.	R
Goldenrod							
Natural	Shoot Length	3.8 mm	Y	R	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	2.3 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.6 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.4 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-07: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	94 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	52.9 mm	Y	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	4.1 mg	Y	Y	G	The shoot weight was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Weight	1.2 mg	Y	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	20.8 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	18.8 mm	R	R	G	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	R
	Shoot Weight	3.3 mg	Y	G	G	The shoot weight was significantly lower than REF-02, but not significantly different from REF-03 or REF-04.	G
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	28.4 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	47.3 mm	G	Y	Y	The root length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Shoot Weight	10.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.8 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	3.7 mm	Y	R	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	4.3 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.3 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.2 mg	G	R	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	R

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CC-08: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	89.2 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	79.3 mm	G	Y	Y	The root length was significantly lower than REF-02, but not significantly different from REF-03 and REF-04.	Y
	Shoot Weight	4.4 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	1.8 mg	Y	R	Y	The root weight was significantly lower than the reference sites.	Y
Red Clover							
Natural	Shoot Length	19.3 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	43.8 mm	Y	R	G	root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Shoot Weight	3.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.8 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
White Spruce							
Natural	Shoot Length	30.3 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	84.5 mm	G	G	G	The root length was not significantly different from the reference sites.	G
	Shoot Weight	8 mg	G	G	Y	The shoot weight was significantly lower than REF-04, but was not significantly different from REF-02 and REF-03.	G
	Root Weight	3.4 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	25.7 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	42 mm	G	R	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Shoot Weight	5.2 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.9 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CON-01: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	103.7 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	105 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	6.2 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.1 mg	G	Y	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 and REF-04.	G
Red Clover							
Natural	Shoot Length	23 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	28.9 mm	R	R	G	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	R
	Shoot Weight	3.7 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	30.2 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	67.2 mm	G	G	Y	The root length was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	G
	Shoot Weight	10.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	3.6 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	9.2 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	29.8 mm	G	R	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Shoot Weight	1.7 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.8 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CON-02: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	57.4 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	9.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.4 mg	R	R	Y	The shoot weight was significantly lower than the reference sites.	R
	Root Weight	0.4 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	14.9 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	12.1 mm	R	R	Y	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.7 mg	Y	G	G	The shoot weight was significantly lower than REF-02, but not significantly different from REF-03 or REF-04.	G
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	30.2 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	18.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.9 mg	G	Y	R	The shoot weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Root Weight	0.9 mg	G	Y	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
Goldenrod							
Natural	Shoot Length	4 mm	G	R	Y	The shoot length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Root Length	3.6 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.4 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.2 mg	G	R	R	The root weight was significantly lower than REF-02, but not significantly different from REF-03 or REF-04.	R

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CON-03: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	71.5 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	30.3 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.5 mg	Y	Y	G	The shoot weight was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Weight	0.8 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	17.2 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	34.5 mm	Y	R	G	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Shoot Weight	6.4 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	3.8 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
White Spruce							
Natural	Shoot Length	30.1 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	42.4 mm	G	Y	R	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Shoot Weight	4.1 mg	G	Y	R	The shoot weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Root Weight	1.2 mg	G	G	R	The root weight was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	Y
Goldenrod							
Natural	Shoot Length	6.3 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	11.1 mm	G	R	R	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	R
	Shoot Weight	0.9 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.9 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CON-05: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	81.5 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	79.7 mm	G	Y	Y	The root length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Shoot Weight	3.8 mg	Y	Y	G	The shoot weight was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Weight	1.5 mg	Y	R	Y	The root weight was significantly lower than the reference sites.	Y
Red Clover							
Natural	Shoot Length	12.8 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	10.2 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.1 mg	R	G	Y	The shoot weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	31.5 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	35.2 mm	Y	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	5.2 mg	G	G	Y	The shoot weight was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	G
	Root Weight	1 mg	G	Y	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
Goldenrod							
Natural	Shoot Length	5.5 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	9.6 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.5 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	1.4 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CON-06: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	79.4 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	29.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.9 mg	Y	Y	G	The shoot weight was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Weight	0.9 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	11.4 mm	Y	R	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	9.5 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.4 mg	Y	G	Y	The shoot weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	26.9 mm	G	Y	Y	The shoot length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Root Length	10.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.6 mg	G	Y	R	The shoot weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Root Weight	0.6 mg	G	R	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	R
Goldenrod							
Natural	Shoot Length	6.3 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	6.7 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.9 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	2.2 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Historically Amended Soil							
CON-07*: Ranked Moderately Impacted							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	90.9 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	92.3 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	5.0 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.0 mg	G	R	Y	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
Red Clover							
Natural	Shoot Length	28.8 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	54.7 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	4.4 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	1.4 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
White Spruce							
Natural	Shoot Length	31.7 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	56.1 mm	G	Y	Y	The root length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Shoot Weight	3.9 mg	G	Y	R	The shoot weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Root Weight	0.9 mg	G	Y	R	The root weight was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
Goldenrod							
Natural	Shoot Length	30.8 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	78.5 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	11.3 mg	G	Y	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Weight	1.1 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
Earthworms							
Natural	progeny (number)	2.4	R	–	G	The number of juveniles was significantly lower than REF-02, but not significantly different from REF-04.	R
	weight per indv	2.4 mg	G	–	R	The individual weight was significantly lower than REF-04, but not significantly different from REF-02.	R

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

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
CON-08: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	61.9 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	17.1 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.9 mg	Y	Y	Y	The shoot weight was significantly lower than the reference sites.	Y
	Root Weight	0.7 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	16 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	8.9 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.1 mg	Y	G	Y	The shoot weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	23.7 mm	Y	Y	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	9.1 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.6 mg	Y	R	R	The shoot weight was significantly lower than the reference sites.	R
	Root Weight	0.4 mg	Y	R	R	The root weight was significantly lower than the reference sites.	R
Goldenrod							
Natural	Shoot Length	4 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	4 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	2.1 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	1.1 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
FB-01: Ranked Severely Impacted - Red							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	43.9 mm	R	R	Y	The shoot length was significantly lower than the reference sites.	R
	Root Length	20.7 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	1.2 mg	R	R	R	The shoot weight was significantly lower than the reference sites.	R
	Root Weight	0.5 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	–	R	R	R	There was no emergence of red clover at FB-01.	R
	Root Length	–	R	R	R	There was no emergence of red clover at FB-01.	R
	Shoot Weight	–	R	R	R	There was no emergence of red clover at FB-01.	R
	Root Weight	–	R	R	R	There was no emergence of red clover at FB-01.	R
White Spruce							
Natural	Shoot Length	28.5 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	65.2 mm	G	G	Y	The root length was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	G
	Shoot Weight	7.8 mg	G	G	Y	The shoot weight was significantly lower than REF-04, but was not significantly different from REF-02 and REF-03.	G
	Root Weight	2.6 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	3.7 mm	Y	R	Y	The shoot length was significantly lower than the reference sites.	Y
	Root Length	4 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.1 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.3 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
FB-02: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	104.5 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	79.8 mm	G	Y	Y	The root length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Shoot Weight	5.8 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.9 mg	R	R	R	The root weight was significantly lower than the reference sites.	R
Red Clover							
Natural	Shoot Length	20.3 mm	G	Y	G	The shoot length was significantly lower than REF-02, but not significantly different from REF-03 or REF-04.	G
	Root Length	39.3 mm	Y	R	G	The root length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Shoot Weight	4.7 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.4 mg	R	G	Y	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	Y
White Spruce							
Natural	Shoot Length	12.6 mm	R	R	R	The shoot length was significantly lower than the reference sites.	R
	Root Length	17.2 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	0.3 mg	R	R	R	The shoot weight was significantly lower than the reference sites.	R
	Root Weight	0.4 mg	Y	R	R	The root weight was significantly lower than the reference sites.	R
Goldenrod							
Natural	Shoot Length	6.5 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	17 mm	G	R	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Shoot Weight	0.9 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.5 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
FB-03: Ranked Moderately Impacted - Yellow							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	84.5 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	97.6 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	5.2 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.3 mg	G	Y	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 and REF-04.	G
Red Clover							
Natural	Shoot Length	12.8 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	8 mm	R	R	R	The root length was significantly lower than the reference sites.	R
	Shoot Weight	3.2 mg	Y	G	G	The shoot weight was significantly lower than REF-02, but not significantly different from REF-03 and REF-04.	G
	Root Weight	0.3 mg	R	G	R	The root weight was significantly lower than REF-02 and REF-04, but not significantly different from REF-03.	R
White Spruce							
Natural	Shoot Length	29.8 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	77.9 mm	G	G	Y	The root length was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	G
	Shoot Weight	9.7 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	3.2 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	4.3 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	17.2 mm	G	R	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Shoot Weight	1.3 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	0.9 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
FB-05: Ranked Low to Not Impacted - Green							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	90.1 mm	Y	Y	G	The shoot length was significantly lower than REF-02 and REF-03, but not significantly different from REF-04.	Y
	Root Length	90.7 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	5.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.2 mg	G	Y	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 and REF-04.	G
Red Clover							
Natural	Shoot Length	25.3 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	52.4 mm	G	Y	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Shoot Weight	5.1 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	1.2 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
White Spruce							
Natural	Shoot Length	30.5 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	97.2 mm	G	G	G	The root length was not significantly different from the reference sites.	G
	Shoot Weight	8.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	2.6 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	6.8 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	16.7 mm	G	R	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Shoot Weight	1.2 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	1.2 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

Approach 1: Comparison of Test Sites to the Reference Sites - Natural Soil							
FB-06: Ranked Low to Not Impacted - Green							
Endpoint		**Value**	**REF-02**	**REF-03**	**REF-04**	**Comments**	**Final**
Northern Wheatgrass							
Natural	Shoot Length	104.3 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	147.1 mm	G	G	G	The root length was not significantly different from the reference sites.	G
	Shoot Weight	5.5 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	3 mg	G	Y	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 and REF-04.	G
Red Clover							
Natural	Shoot Length	19.5 mm	G	Y	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	G
	Root Length	51.1 mm	G	R	G	The root length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Shoot Weight	3.9 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	0.8 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
White Spruce							
Natural	Shoot Length	28.8 mm	G	G	G	The shoot length was not significantly different from the reference sites.	G
	Root Length	74.6 mm	G	G	Y	The root length was significantly lower than REF-04, but not significantly different from REF-02 or REF-03.	G
	Shoot Weight	9.1 mg	G	G	G	The shoot weight was not significantly different from the reference sites.	G
	Root Weight	3.3 mg	G	G	G	The root weight was not significantly different from the reference sites.	G
Goldenrod							
Natural	Shoot Length	6.5 mm	G	R	G	The shoot length was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Length	13.7 mm	G	R	Y	The root length was significantly lower than REF-03 and REF-04, but not significantly different from REF-02.	Y
	Shoot Weight	0.9 mg	G	R	G	The shoot weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y
	Root Weight	1 mg	G	R	G	The root weight was significantly lower than REF-03, but not significantly different from REF-02 or REF-04.	Y

APPENDIX GF-9-C

APPROACH 2: COMPARISONS BETWEEN THE TEST SITES AND REF_{MEAN}

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-01: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	82.1 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	22.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.8 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	18.9 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	10 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.7 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	24.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	10.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.8 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.5 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	2 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-02: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	83.7mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	23.2 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.4 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	18.2 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	13.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.3 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	28 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	35.5 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	4.8 mg	Y	The mean shoot weight in natural soil was lower than REF_{mean}.
	Root Weight	1 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	2.7 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	2.4 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.4 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-03: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	66.5 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	7.5 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	13.2 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	8.5 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	4.1 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.5 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	18.6 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	4.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.3 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	2.5 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	–	R	Golden rod seedlings emerged, but did not grow roots or survive.
	Shoot Weight	0.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	–	R	Golden rod seedlings emerged, but did not grow roots or survive.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-04: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	76.8 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	22.7 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	18.2 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	11.7 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.7 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	29.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	32.6 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	8.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.3 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	2.4 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	3.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-06: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	98.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	73.5 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	4.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.0 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	22 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	20.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.9 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.6 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	25 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	12.4 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.1 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	3.8 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	2.3 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.6 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-07: Ranked Severely Impacted/(Modetately Impacted) - Red/Yellow				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	94 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	52.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	4.1 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	1.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	20.8 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	18.8 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.3 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	28.4 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	47.3 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	10.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.8 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	3.7 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	4.3 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CC-08: Ranked Moderately Impacted - Yellow				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	89.2 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	79.3 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	4.4 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	1.8 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	19.3 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	43.8 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	3.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.8 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
White Spruce				
Natural	Shoot Length	30.3 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	84.5 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	8 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	3.4 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	25.7 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	42 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	5.2 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CON-01: Ranked Moderately Impacted - Yellow				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	103.7mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	105 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	6.2 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.1 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	23 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	28.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.7 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	30.2 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	67.2 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	10.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	3.6 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	9.2 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	29.8 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	1.7 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.8 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CON-02: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	57.4 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	9.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.4 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	14.9 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	12.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.7 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	30.2 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	18.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	4 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	3.6 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.4 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.2 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CON-03: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	71.5 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	30.3 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.5 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.8 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	17.2 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	34.5 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	6.4 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	3.8 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
White Spruce				
Natural	Shoot Length	30.1 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	42.4 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	4.1 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	1.2 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	6.3 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	11.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CON-05: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	81.5 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	79.7 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	3.8 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	1.5 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	12.8 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	10.2 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.1 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	31.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	35.2 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	5.2 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	1 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	5.5 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	9.6 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.5 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	1.4 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CON-06: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	79.4 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	29.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.9 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	11.4 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	9.5 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.4 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	26.9 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	10.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	3.6 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.6 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	6.3 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	6.7 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	2.2 mg	G	The mean root weight in natural soil was similar to REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Historically Amended Soil				
CON-07*: Ranked Moderately Impacted - Yellow				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	90.9 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	92.3 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	5.0 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.0 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	28.8 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	54.7 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	4.4 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	1.4 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
White Spruce				
Natural	Shoot Length	31.7 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	56.1 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	3.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	30.8 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	78.5 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	11.3 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	1.1 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Earthworms				
Natural	progeny (#)	2.4	R	The number of juveniles in historically amended soil was much lower than REF_{mean} for pH-adjusted soil.
	weight per ind	2.4 mg	R	The individual weight in historically amended soil was much lower than REF_{mean} for pH-adjusted soil.

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

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
CON-08: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	61.9 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	17.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.7 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	16 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	8.9 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.1 mg	Y	The mean shoot weight in natural soil was slightly lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	23.7 mm	Y	The mean shoot length in natural soil was slightly lower than REF_{mean}.
	Root Length	9.1 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.6 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	4 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	4 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	2.1 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	1.1 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
FB-01: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	43.9 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	20.7 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	1.2 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.5 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	–	R	There was no emergence of red clover in natural soil at FB-01.
	Root Length	–	R	There was no emergence of red clover in natural soil at FB-01.
	Shoot Weight	–	R	There was no emergence of red clover in natural soil at FB-01.
	Root Weight	–	R	There was no emergence of red clover in natural soil at FB-01.
White Spruce				
Natural	Shoot Length	28.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	65.2 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	7.8 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.6 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	3.7 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	4 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.1 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.3 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
FB-02: Ranked Severely Impacted - Red				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	104.5mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	79.8 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	5.8 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	20.3 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	39.3 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	4.7 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	12.6 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	17.2 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.4 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.
Goldenrod				
Natural	Shoot Length	6.5 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	17 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.5 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
FB-03: Ranked Moderately Impacted - Yellow				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	84.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	97.6 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	5.2 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.3 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	12.8 mm	Y	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	8 mm	R	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	3.2 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.3 mg	R	The mean root weight in natural soil was slightly lower than REF_{mean}.
White Spruce				
Natural	Shoot Length	29.8 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	77.9 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	9.7 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	3.2 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	4.3 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	17.2 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	1.3 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	0.9 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
FB-05: Ranked Moderately Impacted - Yellow				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	90.1 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	90.7 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	5.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.2 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.
Red Clover				
Natural	Shoot Length	25.3 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	52.4 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	5.1 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	1.2 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
White Spruce				
Natural	Shoot Length	30.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	97.2 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	8.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	2.6 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	6.8 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	16.7 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	1.2 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	1.2 mg	Y	The mean root weight in natural soil was slightly lower than REF_{mean}.

Approach 2: Comparison of Test Sites to REF_{mean} - Natural Soil				
FB-06: Ranked Low to Not Impacted - Green				
Endpoint		**Value**	**REF_{mean}**	**Comments**
Northern Wheatgrass				
Natural	Shoot Length	104.3mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	147.1mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	5.5 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	3 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Red Clover				
Natural	Shoot Length	19.5 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	51.1 mm	Y	The mean root length in natural soil was slightly lower than REF_{mean}.
	Shoot Weight	3.9 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	0.8 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
White Spruce				
Natural	Shoot Length	28.8 mm	G	The mean shoot length in natural soil was similar to REF_{mean}.
	Root Length	74.6 mm	G	The mean root length in natural soil was similar to REF_{mean}.
	Shoot Weight	9.1 mg	G	The mean shoot weight in natural soil was similar to REF_{mean}.
	Root Weight	3.3 mg	G	The mean root weight in natural soil was similar to REF_{mean}.
Goldenrod				
Natural	Shoot Length	6.5 mm	R	The mean shoot length in natural soil was much lower than REF_{mean}.
	Root Length	13.7 mm	R	The mean root length in natural soil was much lower than REF_{mean}.
	Shoot Weight	0.9 mg	R	The mean shoot weight in natural soil was much lower than REF_{mean}.
	Root Weight	1 mg	R	The mean root weight in natural soil was much lower than REF_{mean}.

APPENDIX GF-9-D

OVERALL LOE RANKING: COMBINING THE TWO APPROACHES

CC-01: Ranked Severely Impacted - Red

The test species did not grow well in the natural soil. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil.			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	R	White Spruce	Natural	R
Goldenrod	Natural	R	Goldenrod	Natural	R

CC-02: Ranked Severely Impacted - Red

The test species did not grow well in the natural soil. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil.			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	R	Red Clover	Natural	R
White Spruce	Natural	Y	White Spruce	Natural	R
Goldenrod	Natural	R	Goldenrod	Natural	R

CC-03: Ranked Severely Impacted - Red

The test species did not grow well in the natural soil. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil .			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	Y	Northern Wheatgrass	Natural	R
Red Clover	Natural	Y	Red Clover	Natural	Y
White Spruce	Natural	R	White Spruce	Natural	R
Goldenrod	Natural	R	Goldenrod	Natural	R

CC-04: Ranked Severely Impacted - Red

The test species did not grow well in the natural soil. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil.			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	R	Red Clover	Natural	R
White Spruce	Natural	Y	White Spruce	Natural	Y
Goldenrod	Natural	R	Goldenrod	Natural	R

CC-06: Ranked Moderately Impacted / Severely Impacted - Yellow/Red

The test species had moderately to greatly reduced performance in the natural soil. There was agreement between the two approaches with the exception of the performance of goldenrod.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil.			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	Y	Northern Wheatgrass	Natural	Y
Red Clover	Natural	Y	Red Clover	Natural	Y
White Spruce	Natural	R	White Spruce	Natural	R
Goldenrod	Natural	Y	Goldenrod	Natural	R

CC-07: Ranked Severely Impacted - Red

The majority of test species did not grow well in the natural soil, with the exception of white spruce. There was agreement between the two approaches with the exception of red clover in natural soil.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
Most species did not perform well in natural soil, although white spruce did grow well.			Most species did not perform well in natural soil, although white spruce did grow well.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	R	Goldenrod	Natural	R

CC-08: Ranked Moderately Impacted - Yellow

The test species had moderately reduced or similar performance to the reference sites in the natural soil. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
In natural soil, red clover and white spruce performed well, while the other plants performed slightly lower than the reference sites.			The performance of the test species was similar to or slightly lower than REF_{mean}.		
Northern Wheatgrass	Natural	Y	Northern Wheatgrass	Natural	Y
Red Clover	Natural	G	Red Clover	Natural	G
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	Y	Goldenrod	Natural	Y

CON-01: Ranked Moderately Impacted - Yellow

The performance of northern wheatgrass and white spruce was similar to the reference sites, while the performance of goldenrod and red clover was moderately to greatly lower.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of the plant species in natural soil was similar to or slightly lower than the reference sites.			Although northern wheat grass and white spruce performed well in natural soil, golden rod and red clover did not.		
Northern Wheatgrass	Natural	G	Northern Wheatgrass	Natural	G
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	Y	Goldenrod	Natural	R

CON-02: Ranked Severly Impacted - Red

The majority of test species had moderately to greatly reduced performance in the natural soil. There was agreement between the two approaches with the exception of the performance of white spruce and red clover.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of the test species was moderately to greatly reduced in comparison to the reference sites			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	Y	White Spruce	Natural	R
Goldenrod	Natural	R	Goldenrod	Natural	R

CON-03: Ranked Moderately Impacted / Severely Impacted - Yellow/Red

The performance of the majority of test species was moderately to greatly reduced in comparison to the reference sites in natural soil. There was agreement between the two approaches, with the exceptions of red clover and goldenrod.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of the test species was moderately lower to much lower than the reference sites with the exception of red clover in natural soil, which grew well.			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	G	Red Clover	Natural	Y
White Spruce	Natural	Y	White Spruce	Natural	Y
Goldenrod	Natural	Y	Goldenrod	Natural	R

CON-05: Ranked Moderately Impacted / Severely Impacted - Yellow/Red

The majority of test species did not grow well in the natural soil. There was agreement between the two approaches only with respect to Northern Wheatgrass.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of the test species in natural soil was moderately reduced in comparison to the reference sites.			The test species did not perform well in natural soil.		
Northern Wheatgrass	Natural	Y	Northern Wheatgrass	Natural	Y
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	Y	White Spruce	Natural	R
Goldenrod	Natural	Y	Goldenrod	Natural	R

CON-06: Ranked Severely Impacted - Red

The performance of the test species in natural soil was moderately to greatly reduced in comparison to the reference sites. There was agreement between the two approaches, with the exceptions of red clover and goldenrod in natural soil.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of test species was moderately to greatly lower than the reference sites in natural and pH-amended soil.			The test species did not perform well in natural soil and many parameters in pH amended soil were lower than REF_{mean}.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	R	White Spruce	Natural	R
Goldenrod	Natural	Y	Goldenrod	Natural	R

CON-07*: Ranked Moderately Impacted - Yellow

There was agreement between the approaches on the performance of northern wheatgrass, which performed moderately lower; red clover, which performed well; and earthworms, which performed poorly in comparison to the reference sites. The use of the two approaches shows that the performances of white spruce and goldenrod were on the cusp between rankings, resulting in a ranking of moderately impacted for the site. CON-07 was not included in the final site rankings.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of northern wheatgrass and white spruce was moderately lower than the reference sites, but red clover and golden rod were similar. Earthworms did not grow or reproduce well in this historically amended soil.			The performance of northern wheatgrass and goldenrod was moderately lower than REF_{mean}, while white spruce was much lower. Red clover grew well. Earthworms did not grow or reproduce well in this historically amended soil, although there was a thriving population at the site.		
Northern Wheatgrass	Natural	Y	Northern Wheatgrass	Natural	Y
Red Clover	Natural	G	Red Clover	Natural	G
White Spruce	Natural	Y	White Spruce	Natural	R
Goldenrod	Natural	G	Goldenrod	Natural	Y
Earthworm	Natural	R	Earthworm	Natural	R

* 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 - Red

The majority of test species did not grow well in the natural soil, with the exception of northern wheatgrass. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil.			The test species did not perform well in natural soil in comparison to REF_{mean}.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	Y	Red Clover	Natural	R
White Spruce	Natural	R	White Spruce	Natural	R
Goldenrod	Natural	Y	Goldenrod	Natural	R

FB-01: Ranked Severely Impacted - Red

The test species did not grow well in the natural soil, with the exception of white spruce. There was agreement between the two approaches with the exception of goldenrod.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The test species did not perform well in natural soil, with the exception of white spruce.			Although white spruce grew well, red clover did not emerge in natural soil and most other test species performed poorly.		
Northern Wheatgrass	Natural	R	Northern Wheatgrass	Natural	R
Red Clover	Natural	R	Red Clover	Natural	R
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	Y	Goldenrod	Natural	R

FB-02: Ranked Moderately Impacted /Severely Impacted - Yellow/Red

All of the test species had moderately to greatly reduced performance in the natural soil. There was agreement between the two approaches with the exception of the performance of goldenrod.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
The performance of the test species in the natural soil was moderately to greatly lower than the reference sites.			The test species did not perform well in natural soil compared to REF_{mean}.		
Northern Wheatgrass	Natural	Y	Northern Wheatgrass	Natural	Y
Red Clover	Natural	Y	Red Clover	Natural	Y
White Spruce	Natural	R	White Spruce	Natural	R
Goldenrod	Natural	Y	Goldenrod	Natural	R

FB-03: Ranked Moderately Impacted / Severely Impacted - Yellow/Red

With the exceptions of red clover and goldenrod in natural soil, the performance of the plant species in natural soil was similar to the reference sites. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
Although northern wheat grass and white spruce performed well, the performance of red clover and golden rod in natural soil was much lower than the reference sites.			Although northern wheat grass and white spruce performed well, the performance of red clover and golden rod in natural soil was much lower than REF_{mean}.		
Northern Wheatgrass	Natural	G	Northern Wheatgrass	Natural	G
Red Clover	Natural	R	Red Clover	Natural	R
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	Y	Goldenrod	Natural	R

FB-05: Ranked Low to Not Impacted /Moderately Impacted - Green/Yellow

The performance of the majority of test species in natural soil was similar to or moderately lower than the reference sites, with the exception of goldenrod in Approach 2. There was agreement between the two approaches, with the exceptions of northern wheatgrass and goldenrod.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
With the exception of goldenrod, the performance of the plant species in natural soil was similar to the reference sites.			Both red clover and white spruce performed well in natural soil, and northern wheatgrass was slightly lower than REFmean. Golden rod did not perform well.		
Northern Wheatgrass	Natural	G	Northern Wheatgrass	Natural	Y
Red Clover	Natural	G	Red Clover	Natural	G
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	Y	Goldenrod	Natural	R

FB-06: Ranked Low to Not Impacted - Green

The majority of test species grew well in the natural soil, with the exception of goldenrod. There was agreement between the two approaches.

Approach 1: Compared to All Reference Sites			Approach 2: Compared to REF_{mean}		
All test preformed well with the exception of golden rod, which did not do well in any soils on the FB transect.			All test preformed well with the exception of golden rod, which did not do well in any soils on the FB transect.		
Northern Wheatgrass	Natural	G	Northern Wheatgrass	Natural	G
Red Clover	Natural	G	Red Clover	Natural	G
White Spruce	Natural	G	White Spruce	Natural	G
Goldenrod	Natural	Y	Goldenrod	Natural	R