Terrestrial Environmental Effects Monitoring

Forest Health Monitoring Program

Procedures Manual

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Wood Buffalo Environmental Association
Terrestrial Environmental Effects Monitoring
Forest Health Monitoring Program
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Detailed procedures are presented in this manual. It is recognized that procedures change, with new procedures and technologies becoming available that can improve the accuracy, precision, and/or efficiency of the measurements and analyses. Practitioners and laboratory managers are encouraged to provide suggested procedure updates and revisions to the TEEM Program Manager. However, changes to procedures in this manual are <u>not</u> permitted unless first authorized by the TEEM Program Manager; this authorization is to be received in writing prior to implementation of any revised procedure. Changes to laboratory procedures may require that the current and proposed new analyses be run concurrently to ensure compatibility and consistency in data over the duration of the monitoring program.

While TEEM personnel participate in and support the air quality and deposition monitoring programs, the majority are the responsibility of the Ambient Air Technical Committee of WBEA, and the methods associated with such programs are not included in this manual.

This 2nd Edition of the TEEM Procedures Manual updates and replaces the first version authored by K. Foster, D. Baines, K. Percy, A. Legge, D. Maynard and V. Chisholm, published in March 2011.

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PROCEDURES

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1	Sample Labelling	
2	Sample Storage & Shipping	
3	Site Information	01 – Site Information E01- Edge Site Information
4	Reference Stake Installation & Geo-Referencing	
5	Tree Numbering & Labelling	
6	*Public Lands Act* Dispositions	
7	Soil Description	10 – Soil Description
8	Soil Sample (Routine) Location & Checklist	11 – Soil Sample Locations
9	Soil Sample Preparation & Weighing	
10	Soil Texture Analysis	
11	Soil pH Analysis	
12	Soil Electrical Conductivity Analysis	
13	Soil Cation Exchange Capacity Analysis	
14	Soil Exchangeable Cations Analysis	
15	Soil BC:Al Calculation	
16	Soil Base Saturation Percentage Calculation	
17	Total Sulphur, Nitrogen & Carbon Analysis	
18	Soil C:N Calculation	
19	Soil Complexed Aluminum & Iron Analysis	
20	Soil Soluble Cations Analysis	
21	Soil Soluble Nitrogen Analysis	
22	Soil Soluble Phosphorus Analysis	
23	Soil Inorganic Sulphur Analysis	
24	Tree Mapping Measurements	02 – Vegetation Plot Map E02 – Edge Plot Map
25	Tree Coring	
26	Tree Core Preparation & Analysis	X05 – Off-Plot Tree Growth Ring Analysis
27	Tree Condition & Health Assessment	04 – Annual Forest Health Assessment X04 – Off-Plot Tree Assessment E04 – Edge Tree Assessment
28	Tree Data	03 – Vegetation Plot Tree Data X03 – Off-Plot Tree Data E03 – Edge Monitoring Site Tree Data
29	Tree Shoot Data	X06 – Off-Plot Tree Softwood Shoot Data E06 – Edge Tree Shoot Data
30	Foliar Sample (Routine) Collection & Checklist	
31	Lichen Tissue Sampling	
32	Tree & Lichen Tissue Sample Preparation	
33	Foliar Tissue Inorganic Sulphur (S_i) Analysis	
34	Foliar Tissue Organic Sulphur (S_o) and S_i:S_o Calculations	

Procedure Number	Procedure Name	TEEM Data Form Number & Name
35	Tree Tissue Elemental Concentrations Analysis	
36	Epicuticular Wax Structure Analysis	
37	Epicuticular Wax Composition Analysis	
38	Plant Community Assessment	08 – Daubenmire Cover Class Assessment 09 – Daubenmire Summary
39	Epiphytic Lichen Community Composition Assessment	07 – Epiphytic Lichen Community Composition

1.0 INTRODUCTION

The Wood Buffalo Environmental Association's Forest Health Monitoring Program, coordinated through the Terrestrial Environmental Effects Monitoring (TEEM) committee, integrates soil, vegetation, air quality and deposition monitoring at locations selected for their sensitivity and/or exposure to anthropogenic air emissions. This program began in the mid-1990s, in response to regulatory requirements associated with Syncrude's 1993 Mildred Lake approval renewal application and public hearing. While the genesis of the program occurred during a process specific to Syncrude, the TEEM program was constituted as a multi-stakeholder initiative.

The premise upon which the jack pine monitoring program has been developed is that exposure to air emissions, and the deposition that results, causes a cascade of effects:

1. Changes in the chemical properties of the soil occur first. These changes may be in the availability of nutrients, the mobilization of aluminum, or both;
2. Changes in vegetation in response to altered soil chemistry. This is expected to first be observed in altered distribution of nutrients and other elements in plant tissues, and later in changes in tree growth; and
3. Altered species composition, as changes in soil chemistry and effects on vegetative growth create new competitive advantages and disadvantages among species at the site.

In 1996 and 1997, a series of jack pine (BOVAR Environmental et al., 1997) and aspen (Conor Pacific Environmental and Landcare Research & Consulting Inc., 1999) sites were examined, and a number of each were established as monitoring sites, primarily with the purpose of monitoring for the effects of acid deposition. Sandy soils under these forest types have relatively low acid buffering capacity, and are expected to react measurably to acidic deposition.

Monitoring began in 1998, with 10 jack pine sites and 10 aspen sites in the program. In 1999, monitoring activities at the aspen sites (with the exception of passive air monitoring) were suspended due to concerns regarding the clonal nature of aspen, specifically the complication that varying clonal composition among aspen sites would have on interpretation of data. Jack pine monitoring sites were added in 2001 (1 site; AMEC Earth & Environmental Limited, 2002b), 2004 (4 sites), 2011 (10 sites) and 2012 (2 sites). Two sites have been lost to development since 1996. As of 2014, there are 25 active jack pine monitoring sites in the program. Monitoring of these jack pine sites occurs on a 6-year sampling cycle.

The jack pine component was developed on the basis of the National Acid Rain Network Early Warning System (ARNEWS), with the majority of the procedures based on the ARNEWS manual (D'Eon et al., 1994). AGRA Earth & Environmental (1999) presented a summary of the ARNEWS protocols as applied to the jack pine and aspen monitoring program. Modifications to some of the measurements and sampling procedures have occurred over the years in response to data acquired, and as scientific knowledge and laboratory methods improved.

Jack pine trees at a stand edge abutting an open area (e.g., wetland) that faces towards the main emissions sources are more exposed to contaminants in the air. Beginning in 2011, a

number of monitoring sites at these exposed stand edges were established for sampling and measurement of key parameters relating to air quality and deposition on a 3-year cycle. Edge monitoring sites are expected to provide an early indication of environmental change relating to exposure to and/or deposition of substances in the air.

Linking soil and vegetation responses to air emissions and deposition requires measurement of air quality and deposition levels. Because of the remoteness of TEEM sites, ambient air quality and deposition monitoring at the sites is difficult and expensive. Expansion of the air and deposition monitoring capacity within the TEEM program has been a focus of WBEA (and TEEM) for the past several years. Initially, a subset of the jack pine and aspen sites were equipped with towers onto which passive monitoring devices for SO_2, NO_x, and O_3 were installed above the tree canopy. Air quality and deposition monitoring has expanded to include a greater number of sites, and to incorporate a greater diversity of monitoring instruments and devices. Quantification of the concentrations of substances in the air, and of the deposition amounts to soil and vegetation, will is an important component of the interpretation of changes in soil and vegetation at TEEM sites in the context of exposure to air emissions and to measured deposition quantities.

The activities required at a jack pine monitoring site, from the site and plot establishment to the routine assessments, measurements and sample collection at the site during routine monitoring, are illustrated in Figures 1a to 1f. These activities form the core of the Forest Health Monitoring Program. At the discretion of the TEEM committee, additional programs may be executed in one or more years; these programs are not shown on the program charts. Whether tasked with completion of the entire program or with only a part thereof, personnel must understand the overall program and their part in it, paying particular attention to the interfaces with those executing other program elements. When in doubt about any aspect of the program or the procedures, consultation with the TEEM Program Manager is required.

The structure of this manual supports the TEEM Committee's contracting approach. Components are grouped by major activity, as each major activity is likely to be conducted by a single researcher, contractor, or contracting team. The division into major activities allows the TEEM Committee to select different contractors for each activity, or a single contractor for the entire program, in any year of monitoring activity.

Because of the longevity of the program (>25 years), and the interval between sampling in program components (up to 6 years), it is certain that personnel tasked with field activities, laboratories contracted for sample analyses, and the membership of the TEEM committee itself, will change over the course of the program. Changes in the personnel involved represents a risk to the program, as the potential for errors and omissions increases, and variations in expertise are expected. Adherence to the procedures presented in this manual are required to minimize the errors, omissions, subjectivity, and variability in data such that the integrity of the monitoring program is preserved and conclusions may be reliably and confidently drawn from the data.

Figure 1.1: Site Establishment

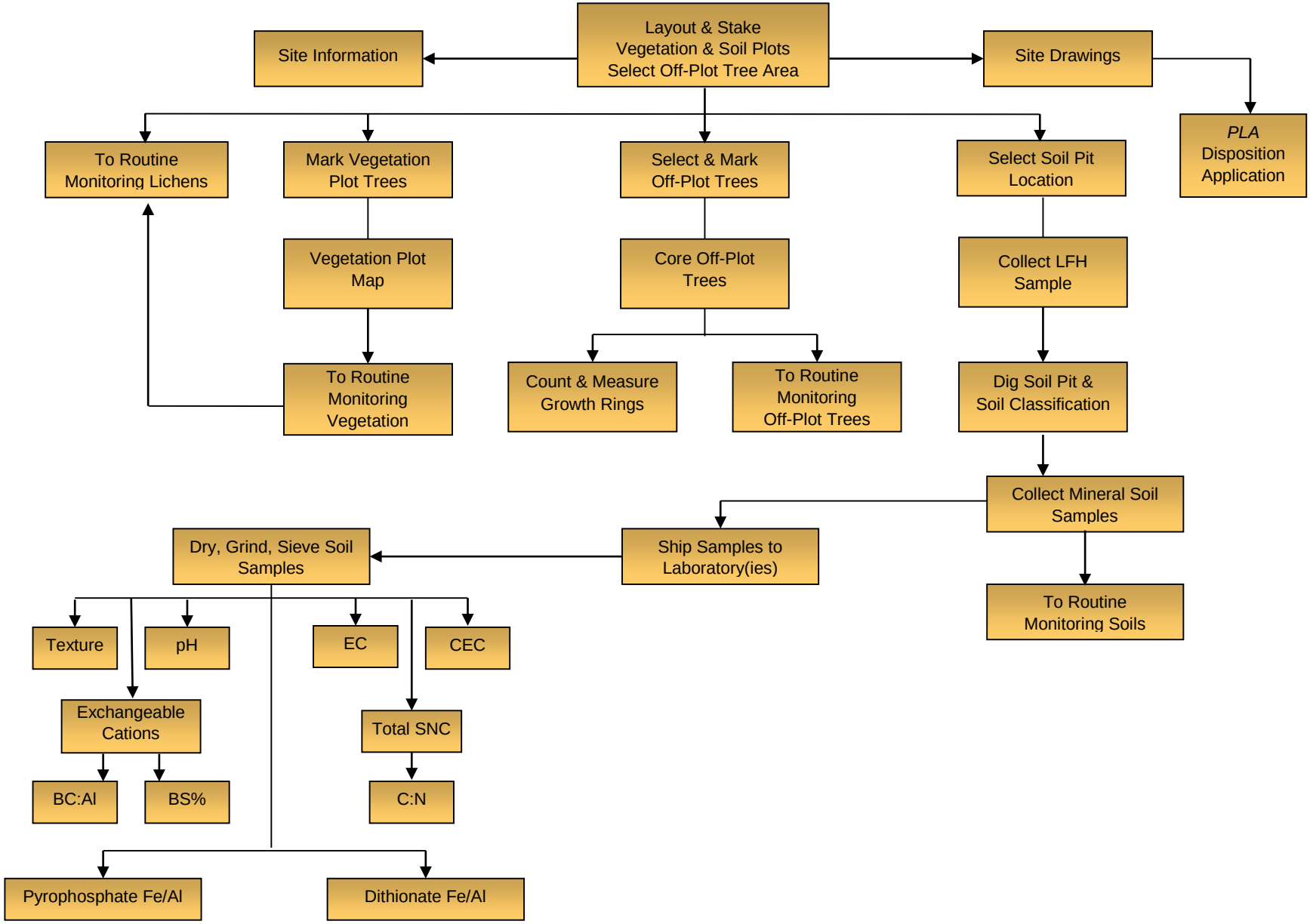


Figure 1.2: Routine Monitoring – Vegetation Plot

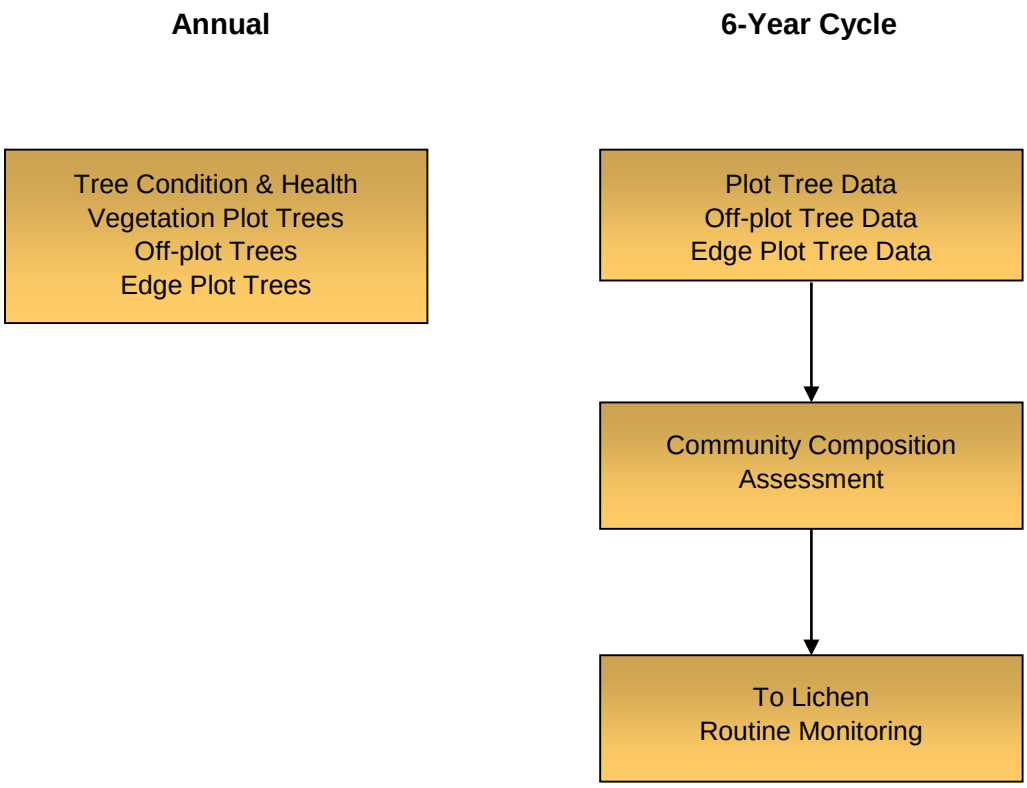


Figure 1.3 Routine Monitoring – Off-Plot Trees

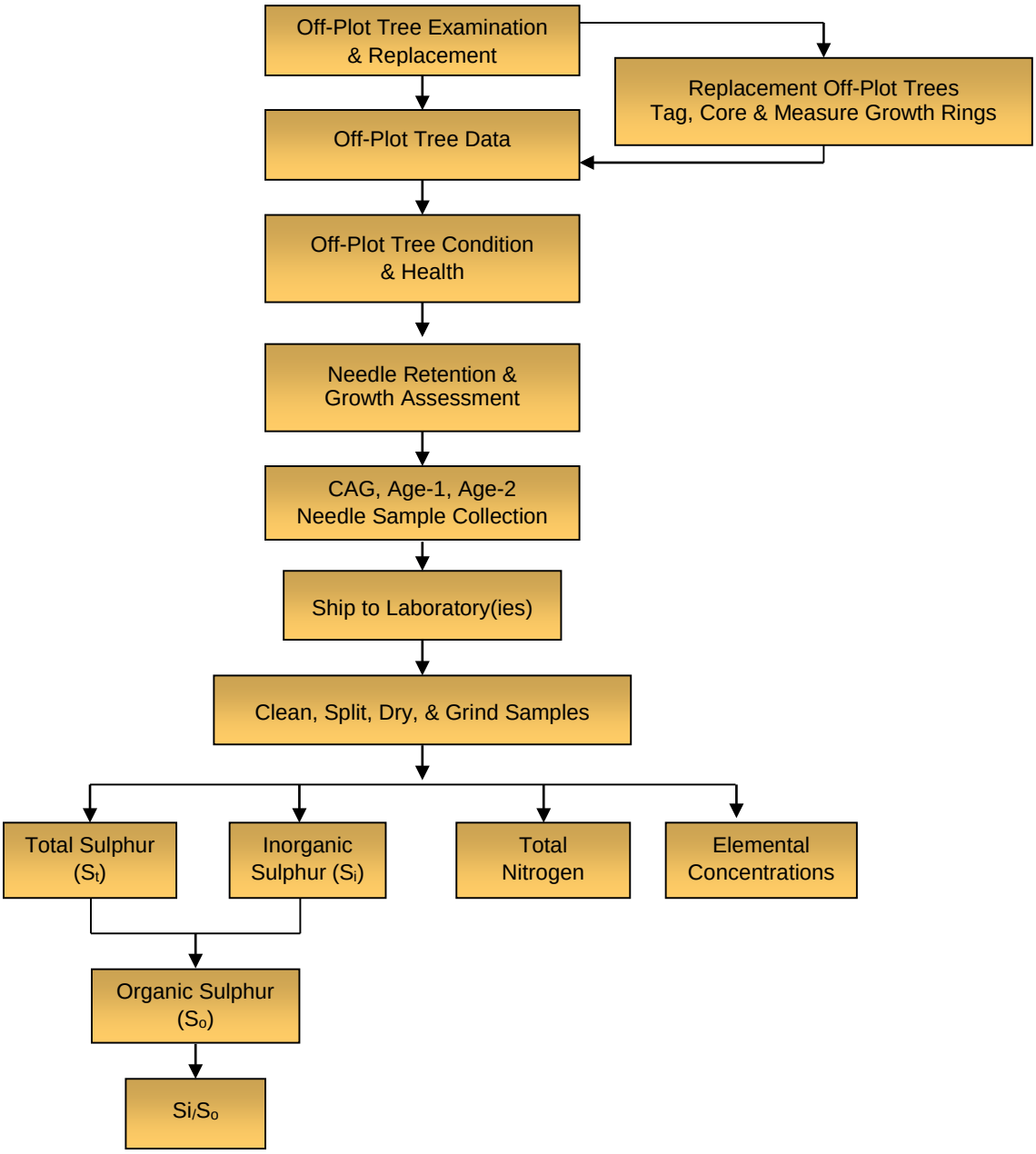


Figure 1.4: Routine Monitoring – Soil Plots

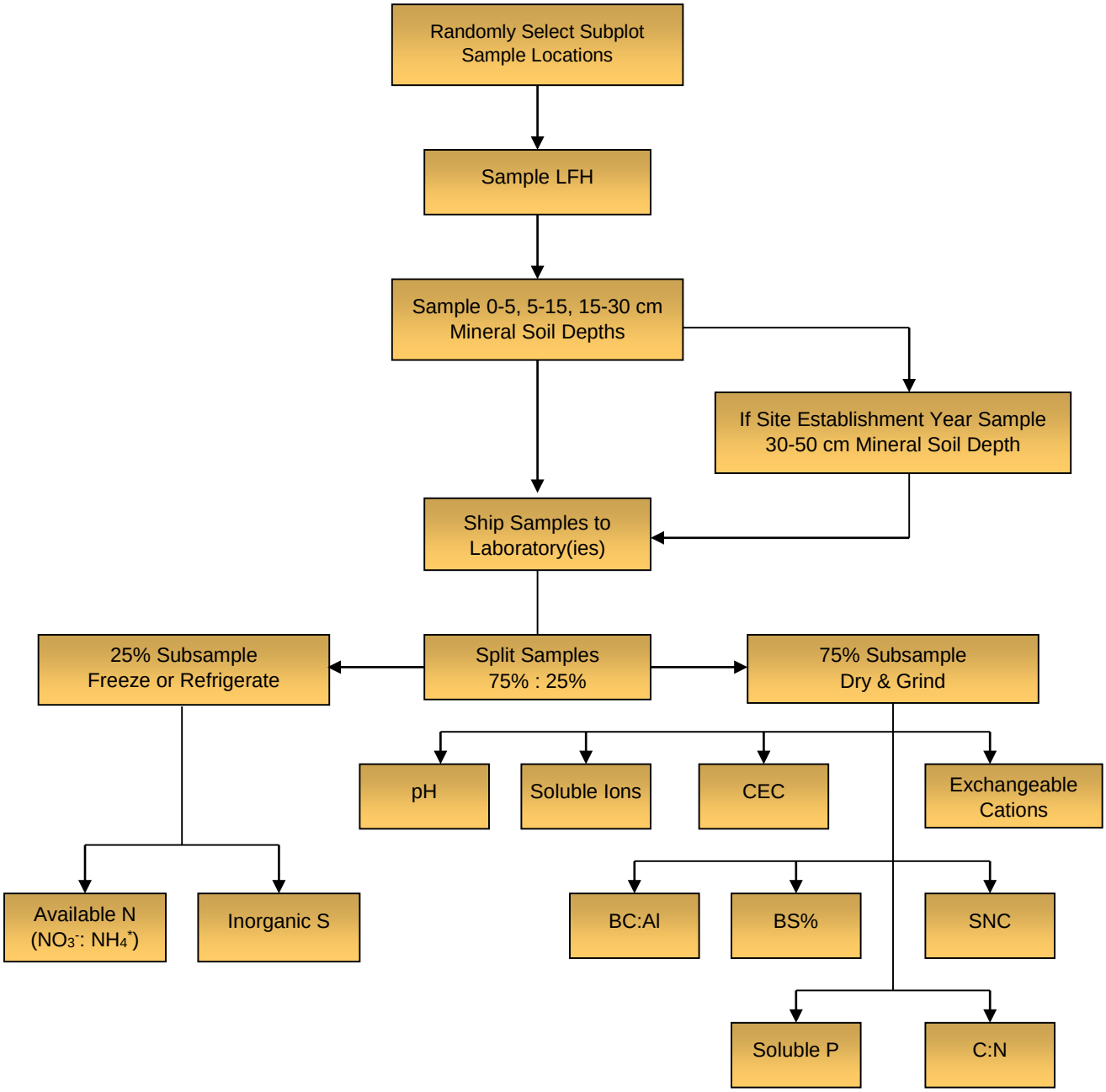


Figure 1.5: Routine Monitoring – Lichens

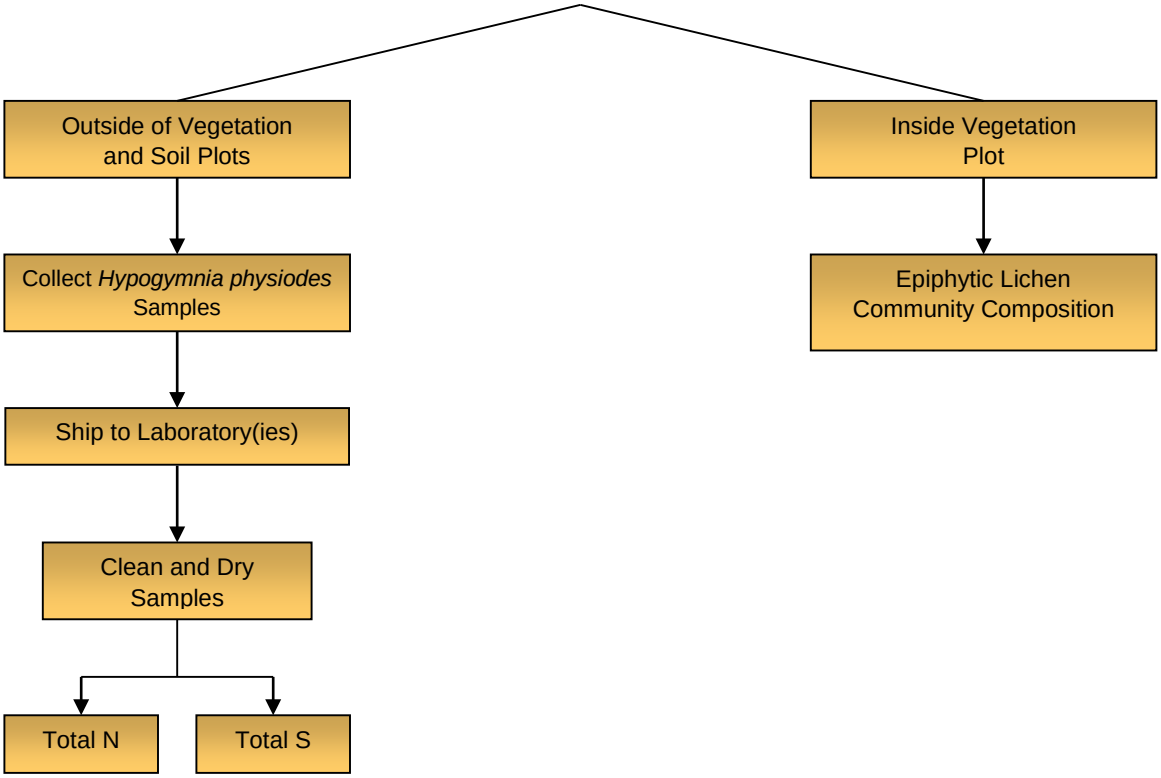
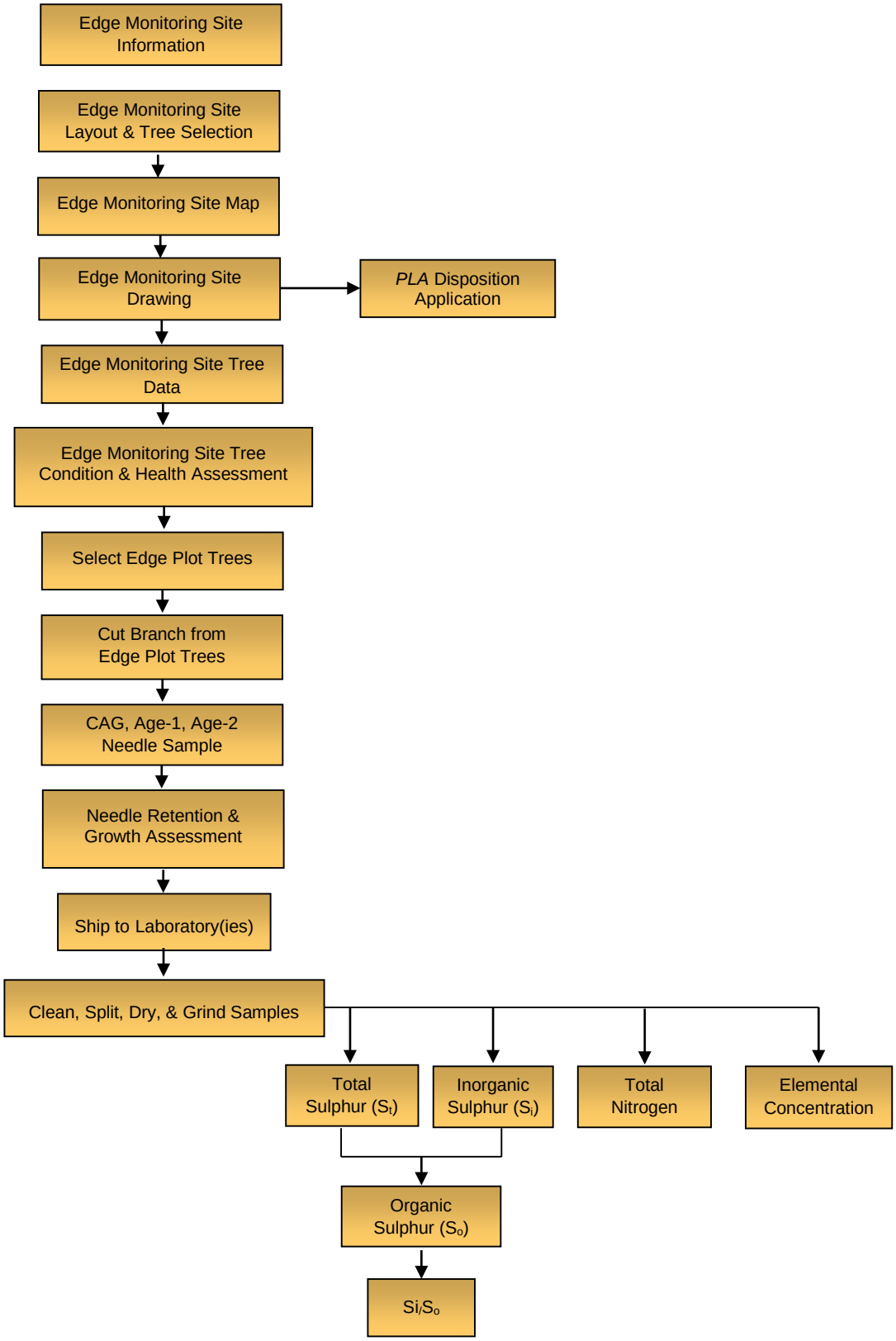


Figure 1.6: Edge Monitoring Site Establishment & Monitoring



2.0 MONITORING SITE NAMING CONVENTION

In the early stages of Forest Health Monitoring Program development, jack pine and aspen monitoring sites were designated using a three-part label, representing: (1) tree species, (2) presumed deposition loading, and (3) site number. Thus, jack pine sites were labelled “JP” and aspen sites “A”, followed by an “H” or “L” (for “high” and “low”, respectively) to designate the presumed acid deposition environment, and lastly a single digit representing the number of the site within the deposition zone. The labels for sites established in 2001 and 2004 did not reference the deposition environment, and the site label was “JP” followed by a 3-digit number beginning with “2”. Through 2011, contractors responsible for evaluating and recommending suitable edge monitoring sites assigned interim site labels.

The site naming convention was consolidated in 2010 to remove reference to deposition zone, and to apply consistent site labelling procedure to new sites selected into the program. Labels assigned to sites established before 2001 were revised, and sites added to the program since 2001 have been given a 5-character designation. All jack pine monitoring sites at the interior of jack pine stands are to have a label that begins with “JP”, and jack pine monitoring sites at the stand edge are to be assigned a label beginning with “JE”. Although monitoring has been suspended at the aspen monitoring sites, the naming convention has been applied to the aspen sites selected in 1997; these sites have a label that begins with “AS”. The 3-digit number that follows the species code represents a unique site number, with the first digit of the three reflecting the year that the site entered the program. Thus:

- the JP100 and AS100 series of sites are those that were established in 1998;
- the JP200 and AS200 series of sites are those that were established between 2001 and 2004; and
- the JP300 series of sites are those that were established in 2011 and 2012.

Jack pine edge monitoring sites will be identified as “JExxx”, following a numerical series like that applied to the interior stand monitoring sites (the JPxxx sites). Thus:

- the JE200 series of jack pine edge monitoring sites are those that were established between 2001 and 2004; and
- the JE300 series of jack pine edge monitoring sites are those that were established in 2011 and 2012.

To date, no aspen edge monitoring sites have been incorporated into the program. The site designation “AExxx” is reserved for aspen edge monitoring sites, should they be added at a later time. Additional series (JP400 to JP900; JE400 to JE900, AS300 and above) are reserved for sites that enter the program in the future.

Historical site names and labels are included in the detailed information compiled for each of the sites, within the WBEA TEEM Site Binder.

3.0 SAMPLE HANDLING

Preservation of sample integrity is critical, as confidence in the results of laboratory analyses may be significantly decreased if samples are suspected of contamination or degradation. Because of the remote locations at which samples are obtained, and the potential lengthy period required to transport samples from the field to the laboratory, care and attention to proper handling from sampling through to analysis (and archive, if appropriate) is required to maximize integrity of collected samples.

Because of the number of samples acquired, the need for specific analyses, and the schedule by which the laboratory results will be required, selection of a laboratory (or laboratories) should be made well in advance of the field program. Laboratory selection should include consideration of the capabilities of the laboratory including use of modern equipment and procedures yielding detection limits appropriate for the analyses, and the implementation of quality assurance and quality control programs. These QA/QC programs should include rigourous adherence to standard laboratory practices, participation in inter-laboratory programs, accreditation, and use of in-house laboratory procedures for validation of analytical procedures. The laboratory(ies) selected should be made aware of all analyses required well in advance of the field program, such that when the samples arrive, laboratory staff are prepared to properly receive them and initiate the analyses or place the samples in appropriate storage.

3.1 Sample Acquisition

3.1.1 Chain-of-Custody

The chain-of-custody process ensures that a sample is in possession of, or has been secured by, a responsible person at all times. A sample is under custody of a responsible individual if:

- it is in possession of the individual;
- it is in view of the individual, after being in the individual's possession; or
- the individual placed it in a designated secure area.

The sample transfers custody only when a responsible individual relinquishes custody by signing and dating the chain-of-custody form, and the receiving individual accepts custody by signing and dating the form. This process of custody transfer occurs every time the samples are transferred from one party to the next, as the samples move from acquisition in the field to the laboratory, and if appropriate, from the laboratory to the sample archive facility.

As a part of the transfer of sample custody to the laboratory, laboratory personnel are to examine each sample to ensure that sample integrity has been preserved (e.g., sample temperature is appropriate, sample seals are intact, the proper signatures are present, the holding times fall within the requirements).

Laboratories may provide a chain-of-custody form, and if so, these are acceptable for use in the TEEM Forest Health Monitoring Program. In some cases, standard forms may not be available,

and forms specific for that component of the Forest Health Monitoring Program will have to be prepared.

Chain-of-custody documentation will be examined closely in the investigation of an apparently anomalous measurement, laboratory analysis or other result. In the absence of a properly executed chain-of-custody process, the apparently anomalous measurement, analysis or result will certainly be discarded, potentially representing an unrecoverable monetary and data cost to the program. Proper attention to the chain-of-custody procedure is a key component of the scientific and public credibility of Forest Health Monitoring Program.

3.1.2 Sample Labelling

The chain-of-custody form is to be filled out in the field, at the time of sample collection. Each sample taken is to be labelled according to the requirements for the sample, according to the **SAMPLE LABELLING PROCEDURE (#1)**. Sample names entered into the chain-of-custody form must match the labels applied to the samples.

3.1.3 TEEM Data Forms

Many of the sample and data collection procedures include completion of a TEEM Data Form. Field personnel are encouraged to make full use of the Remarks field to record observations, sampling conditions that may affect sample integrity, and any observation that may assist in the interpretation of the results of subsequent measurements and analyses. Field personnel are not restricted to use of Remarks field – notes and observations of any kind thought to be of potential use in the TEEM program may be made in a field notebook and forwarded to the TEEM Program Manager.

3.1.4 Sample Inspection

At the end of each field day, each sample taken that day is to be inspected to confirm:

- correct sample labelling, per **SAMPLE LABELLING PROCEDURE (#1)**;
- that sample containers are properly sealed;
- that sample numbers and information are properly recorded on the relevant TEEM Data Form, if required; and
- that the chain-of-custody form is fully and properly completed for each sample,

Corrective actions, such as transferring a sample from a compromised sample container to a new, clean and properly labelled container, or transferring information from a torn, stained and potentially illegible chain-of-custody form to a new form, are to be taken as necessary at the end of each field day. Proper tools must be used to transfer samples, and transfers must be conducted in an environment that will not lead to sample contamination.

3.2 Sample Storage & Shipping

A storage and shipping plan is to be prepared in advance of the initiation of field sample collection. This plan is to be based on the shipping services available in Fort McMurray, and the timetables associated with each service. Consideration of the delivery time at the laboratory(ies) is required, as is coordination with personnel at the laboratory(ies) receiving the samples, to ensure that samples do not sit in a receiving dock or warehouse for an unacceptable period of time.

Due to the remote nature of the sample locations, and the somewhat restricted shipping services available in Fort McMurray, it is generally necessary to store samples for short periods (a few hours, overnight, a few days) before they can be shipped to the appropriate laboratory(ies). Proper storage is required to preserve sample integrity, from initial sample acquisition in the field through to ultimate storage in the TEEM sample archive facility. Shipping services in Fort McMurray include ground (courier, bus) and air (scheduled flights). Ground shipment is preferred, as it is less expensive and can be less restrictive.

The **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)** describes the storage requirements for the samples collected within the Forest Health Monitoring Program, from the time of field collection through to sample archival. Samples are generally held in an interim storage facility for a few days, after which they are packaged and shipped to the laboratory(ies). The receiving laboratory(ies) are to be notified upon shipment so that they are properly prepared to receive the samples. Each laboratory is to be instructed to contact the shipper if the samples do not arrive on the expected date. In this event, the shipper is to immediately notify the TEEM Program Manager, and contact with the shipping company made to initiate a trace on the samples. Lengthy delays in shipment may compromise the entire sample set.

4.0 JACK PINE INTERIOR MONITORING SITE SELECTION & ESTABLISHMENT

4.1 Site Selection Timing

Site selection and establishment activities are to be conducted in the summer. If conducted in the period from August 1 to September 15, soil, plant and lichen sampling may be concurrently conducted with site establishment.

4.2 Jack Pine Interior Monitoring Site Selection Criteria

From the inception of the Forest Health Monitoring Program in 1996 to the present, an increasing focus has been applied to the criteria used in the selection of monitoring sites. The initial set of sites was selected from a pool of candidate sites, with each site in the pool being having met the criteria in place at the time (BOVAR Environmental et al., 1997). The location of the stand within a larger forest landscape and away from the influence of natural and anthropogenic edges, and the size of the stand itself, were criteria adopted from the ARNEWS program (D'Eon et al., 1994). Based on these criteria, the first 10 jack pine monitoring sites were selected, and monitoring plots were established at each of these sites. The selection of sites in 2001 (AMEC Earth & Environmental Limited, 2001) and in 2004 (CE Jones and Associates et al., 2006) was guided by these criteria, leading to additional sites being incorporated into the Forest Health Monitoring Program.

The emphasis on the selection of ecologically analogous sites was increased in the site evaluation process leading up to the 2011 monitoring program. The selection of sites that are as analogous as the environment in the region allows reduces variability within the measured parameters, increasing the ability to detect responses to deposition and exposure to air emissions. The vegetation community is very sensitive to water and nutrient availability and therefore, it is the vegetation community that defines the ecological analogue types (Table 4.2.1). The Type 3 jack pine ecological analogue has been selected as the primary jack pine stand type in which the long-term monitoring plots (vegetation and soil) will be established, and monitored. Type 3 characteristics are highlighted in green shading. Blue shading in the Characteristic and Common Species sections of Table 4.2.1 indicate a much lower or higher presence of characteristic and common species, than are present in Type 3 analogue types. Red shaded cells highlight the presence, and in some cases an abundance, of species that indicate elevated water availability and/or nutrient availability, relative to the xeric, nutrient poor Type 3 jack pine stand type desired for the program. It is recognized that there will be variability around the values associated with species cover in Type 3 sites, but that in order to be considered for inclusion in the program the variability is to be minimal, not extending into the ranges defined by the values shaded in blue and red (i.e., not so large as to cause the site to be reclassified into another ecological analogue type).

Table 4.1: Vegetation Characteristics of Jack Pine Ecological Analogue Types

Species	Ecological Analogue Type									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Characteristic Species										
Pinus banksiana (overstory)	38.0	34.0	32.2	49.0	38.0	31.5	32.0	31.0	22.0	35.0
Pinus banksiana (seedlings)	2.1	0.1	0.1	0.5	1.5	0.1	0.5	0.5	0.5	0.1
Arctostaphylos uva-ursi	10.8	9.0	3.5	9.5	1.7	2.7	0.7	3.2	1.0	14.0
Vaccinium myrtilloides	6.0	6.1	3.4	4.3	4.3	11.8	2.9	16.0	19.0	7.0
Cladina mitis	39.0	14.5	52.5	24.7	37.4	28.5	61.6	49.0	29.0	4.7
Total Characteristic Species	*95.9*	*63.7*	*91.7*	*88.0*	*82.9*	*74.6*	*97.7*	*99.7*	*71.5*	*60.8*
Differential Species										
Alnus crispa		0.1	0.1	7.0		3.8			3.0	
Amelanchier alnifolia	0.6				0.1					0.1
Anemone mulifida	0.4									
Betula papyrifera				0.5						
Cornus canadensis	0.5	2.7	0.1	0.5				0.5		3.2
Elymus innovatus	0.1		0.1	0.3	2.4		0.2	0.8	2.0	1.3
Ledum groenlandicum		1.0				3.0		0.1		
Linnaea borealis	1.2	2.2		0.4		0.5		0.5	8.0	2.4
Lycopodium complanatum	0.5	1.8		3.5		6.0				
Oryzopsis asperifolium				0.2	0.3					
Oryzopsis pungens	0.2	0.1	0.2	0.5	0.3	0.1	0.3	2.2	0.5	0.1
Picea glauca									0.5	
Picea mariana		1.2						0.1		
Poulus tremuloides	0.1			0.3					2.0	
Salix spp.						0.1				
Shepherdia canadensis		0.1	0.3							3.0
Vaccinium vitis-idaea	2.7	8.0	2.3	2.5	0.1	7.2	1.1	3.0	7.0	5.0
Pleurozium schreberia	11.6	18.9	9.4	3.4	37.2		0.1	2.8	9.0	11.0
Cladonia gracilis				0.2	1.5	13.5		1.8	0.5	
Dicranum polysetum	1.5	2.7	2.0	4.1	5.3	0.1			0.5	
Total Differential Species	*19.3*	*38.8*	*14.7*	*23.4*	*47.2*	*34.3*	*1.7*	*12.0*	*33.1*	*26.1*
Common Species										
Maianthemum canadense	0.5	2.8	2.5	2.0	4.0	0.5	1.9	3.3	0.5	
Rosa acicularis	0.7	0.3	0.5	0.1	0.1	0.2	0.1	0.5	0.5	0.1
Polytrichum junbiperinum			0.4	0.6	0.1	0.4	0.1			
Cladina stellaris	1.3	0.1	5.2	7.0	2.0	0.1	1.1	0.5	0.5	0.8
Total Common Species	*2.5*	*3.2*	*8.6*	*9.7*	*6.2*	*1.2*	*3.3*	*4.3*	*1.5*	*0.9*
Total Species Cover	**117.7**	**105.7**	**115.0**	**121.1**	**136.3**	**110.1**	**102.7**	**116.0**	**106.1**	**87.8**

4.3 Jack Pine Interior Monitoring Site Layout & Staking

4.3.1 Vegetation Interior Monitoring Plot Establishment

A defined plot within which jack pine trees are measured and assessed at 6-year intervals is required. Use of defined plots for this type of evaluation is a standard practice in monitoring programs, and the dimensions of the plot used in the Forest Health Monitoring Program is based on the plots used within the Acid Rain National Early Warning System (ARNEWS) program (D'Eon et al., 1994).

A vegetation plot measuring 10 m x 40 m is to be established in the approximate centre of the jack pine stand. The plot is to be a minimum of three tree heights (approximately 50 m) away from the stand edge, seismic lines, roads, and other disturbances. The plot must be representative of the overall stand, including trees of similar age and structure as are present in the stand as a whole, at a density that is representative of the stand.

The corners of this plot, the plot centre, and the midpoints along each axis, are to be staked with a wood stake over which a hollow, white plastic stake is installed. This provides for visual reference points (white stakes), and for detection of the plot corners in the event that the plastic markers are broken or destroyed. The plot is to be divided into four, 20 m x 5 m quadrants. The quadrant that represents best the southwest quadrant is assigned coordinates in "-x, -y" format, and in clockwise rotation, the northwest quadrant is assigned coordinates in "+x, -y" format, the northeast quadrant in "+x, +y" format and the southeast quadrant in "-x, +y" format (Figure 4.1). Each tree within the plot is to be numbered and labelled according to the **TREE NUMBERING & LABELLING PROCEDURE (#5)**.

In 2004, an understory plant community component was added to the jack pine monitoring component of the program. Understory plant community assessments are to continue in the 6-year monitoring cycle of the Forest Health Assessment Program. Assessments of plant community composition are to be made using a series of subplots delineated within the vegetation plot. Ten small (1 m x 0.4 m), two medium (4 m x 1 m), and one large (20 m x 2 m) subplots are to be arranged as shown in Figure 4.1. The corners of the subplots are to be staked using pigtail stakes, with short lengths of flagging tape tied to the top to facilitate visual identification of the subplots.

4.3.2 Soil Plot Establishment

Four soil plots, each divided into four subplots, provide for sufficient sample numbers to support the statistical analysis of the chemical analysis data at a level of sensitivity that allows for a detection of deposition effect(s). This is consistent with the requirements of the Acid Deposition Management Framework (Cumulative Environmental Management Association, 2004). Soil plots are to be a minimum of 10 m from the vegetation plot.

A standard 40 m x 10 m (400 m^2) plot is preferred. In those instances where site characteristics do not permit the establishment of a plot(s) of standard dimensions, any or all of the soil plots at the site may be reduced to 300 m^2 or 225 m^2, by reducing the long dimension from 40 m to 30 m, and the short dimension from 10 m to 7.5 m, as necessary (Figure 4.2).

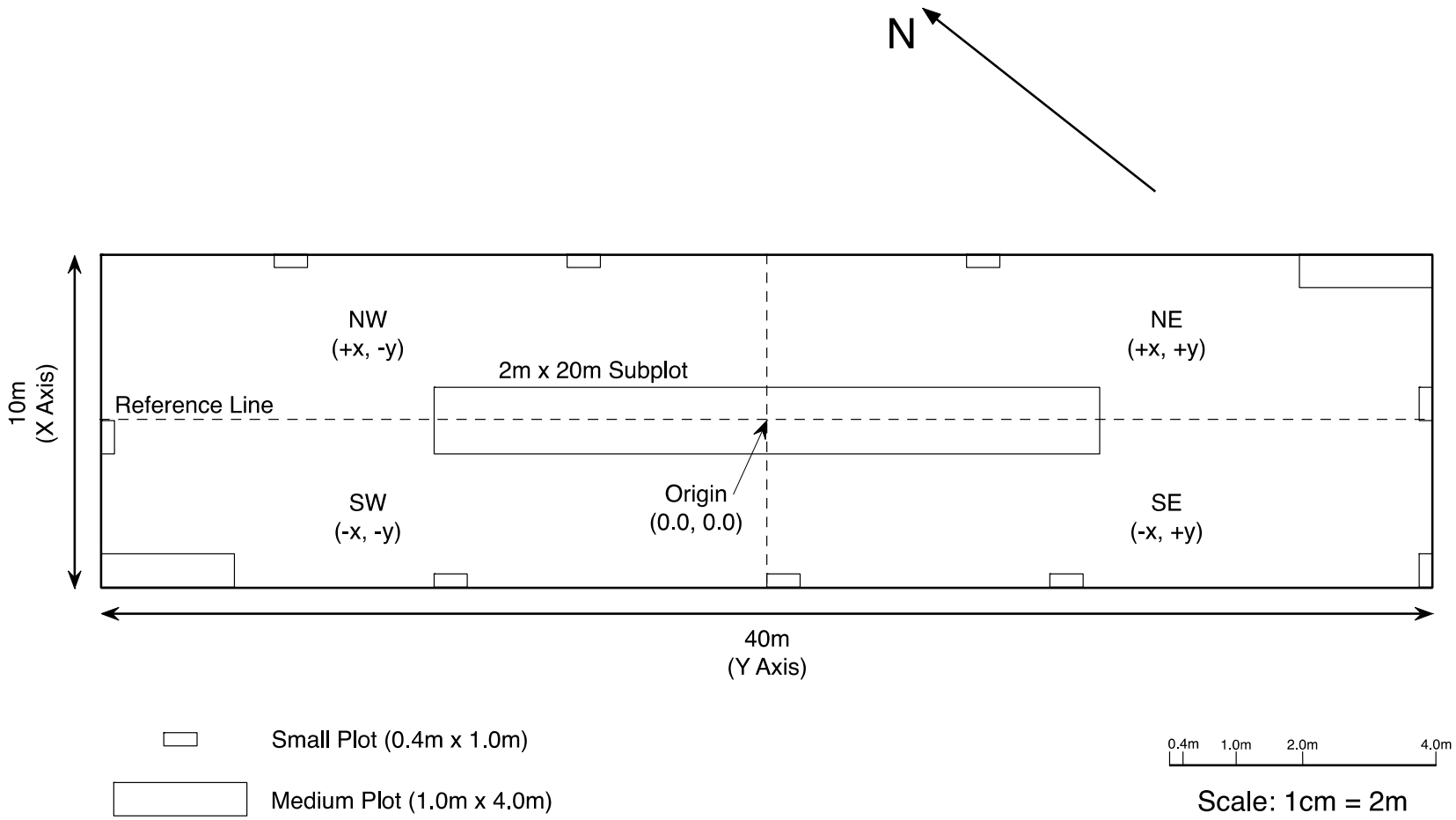


Figure 4.1: Vegetation Plot Layout

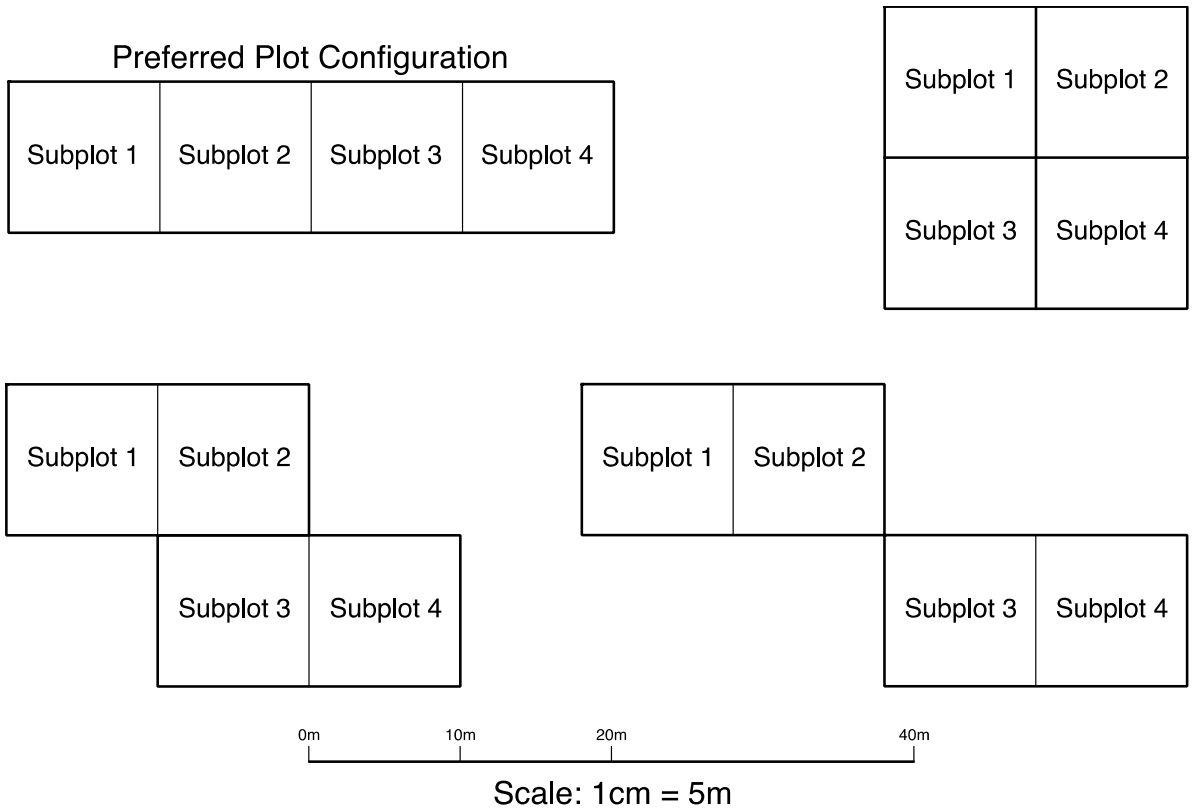


Figure 4.2: Soil Plot Configurations

Each soil plot is to be divided into four subplots. The corners of the plot and each subplot are to be staked with a wood stake over which a hollow, white plastic stake is installed. Use of any kind of metal stake for marking the soil plots is not permitted. This provides for visual reference points (white stakes), and for detection of the plot corners in the event that the plastic markers are broken or destroyed.

Soil plots are to be numbered from “1” to “4” (i.e., “S1” to “S4”), and the four subplots within each soil plot are to be numbered from “1” to “4” (e.g., “S1-1” to “S1-4” for subplots in soil plot “S1”). The subplot nearest the reference stake should be designated subplot number “1”.

In the case where a previously established soil plot becomes unsuitable for continued use, a replacement plot is to be established according to the guidance above. The new soil plot will be numbered “5”, with subplots numbered “S5-1” to “S5-4”. Plot numbers are not to be reused.

4.3.3 Soil Pit Location

The location of the soil pit required for sampling of A and B soil horizons at each new jack pine monitoring site is to be identified during layout and staking. An area of about 3 m x 3 m is to be allowed for the soil pit. The pit is to be a minimum of 10 m from the vegetation plot, and 5 m from any of the soil plots. Once identified, the area is to be undisturbed until the soil pit is dug

and sampled. A soil pit is required only during site establishment, however, its location must be recorded and marked on all site drawings.

4.3.4 Off-Plot Tree Area & Selection of Off-Plot Trees

Trees of the same growth form and in an area of similar density as those in the vegetation plot are to be used for sampling involving destructive techniques (e.g., coring, branch excision). Use of trees outside of the vegetation plot preserves the plot trees, ensuring that the effects of branch harvest do not influence the health of trees that are the core of the jack pine monitoring program.

An area within the stand, outside of the boundaries of the soil and vegetation plots by a minimum of 5 m, is to be identified. The area is to contain 20 or more trees that are similar in height, morphological structure and insect/disease infestation as those that occur within the 10 m x 40 m vegetation plot. Two off-plot tree areas may be identified if site characteristics do not provide for a single off-plot tree area having 20 or more representative trees. The off-plot trees must not be touching trees in the vegetation plot, nor can the off-plot trees lean into the vegetation plot. From the pool of trees in the off-plot area(s), 10 trees that are representative of the trees in the stand are to be selected. These trees are to be numbered and labelled according to **TREE NUMBERING & LABELLING PROCEDURE (#5)**.

4.3.5 Reference Stake

At the completion of plot layout and staking, the reference point is to be selected, and a reference stake installed according to **REFERENCE STAKE INSTALLATION & GEO-REFERENCING PROCEDURE (#4)**. This procedure includes instructions on acquiring site coordinates and measurements necessary to create the plot layout drawing (below).

4.3.6 Interior Monitoring Site – Plot Layout & Site Drawings

The plot layout and site drawings provide critical information for field personnel, and are necessary components of the *Public Lands Act* land use disposition application to Alberta Environment and Sustainable Resource Development. A pair of scale drawings, one showing the details of plot layout and the other the position of the site on the landscape, is required for each monitoring site.

A plot layout drawing is to be prepared at a scale that permits presentation of all plots, the off-plot tree area, the location of the soil pit, and the location of the reference stake on a single letter-sized page. Distances and bearings from the reference stake to the nearest corner of each of the vegetation and soil plots are to be shown. Soil plot and subplot numbers are required. The bearing of the long axis of each of the vegetation and soil plots relative to true North is to be presented; on the soil plots the bearing is to be taken from one of the two subplot “1” corners. The boundary of the off-plot tree area is to be defined using a dashed line. The scale and a scale bar, an arrow showing true North, an arrow showing the bearing (relative to true North) to the each of the oil sands upgrading facilities (Syncrude, Suncor, CNRL, Nexen), and the coordinates of the reference stake are to be included. An example of an acceptable plot layout drawing is presented in Figure 4.3.

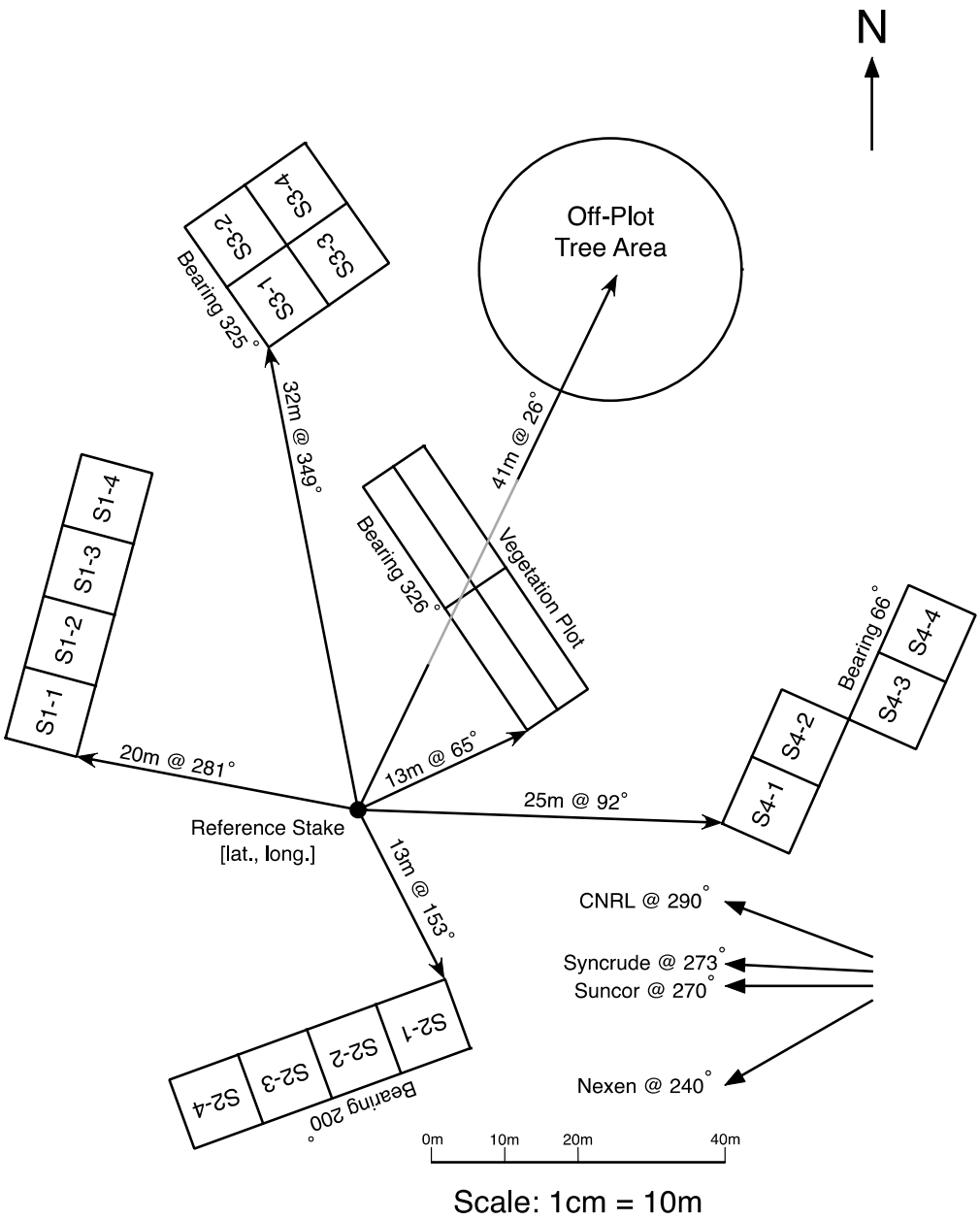


Figure 4.3: Example Plot Layout Drawing

A site drawing showing the location of the plots in a wider context is also required. This drawing is to indicate the location of the helicopter landing site, the trail from the landing site to the plots, nearby cutlines, forest stand edges, the jack pine edge monitoring site (if present), and any other landscape feature in the vicinity of the site. The site drawing is to fit on a single letter-sized page. The scale of this drawing will be dependent on the distance from the plot to other landscape features; the scale and scale bar are to be included. An arrow to true North, and arrows and bearings (relative to true North) to the each of the oil sands upgrading facilities

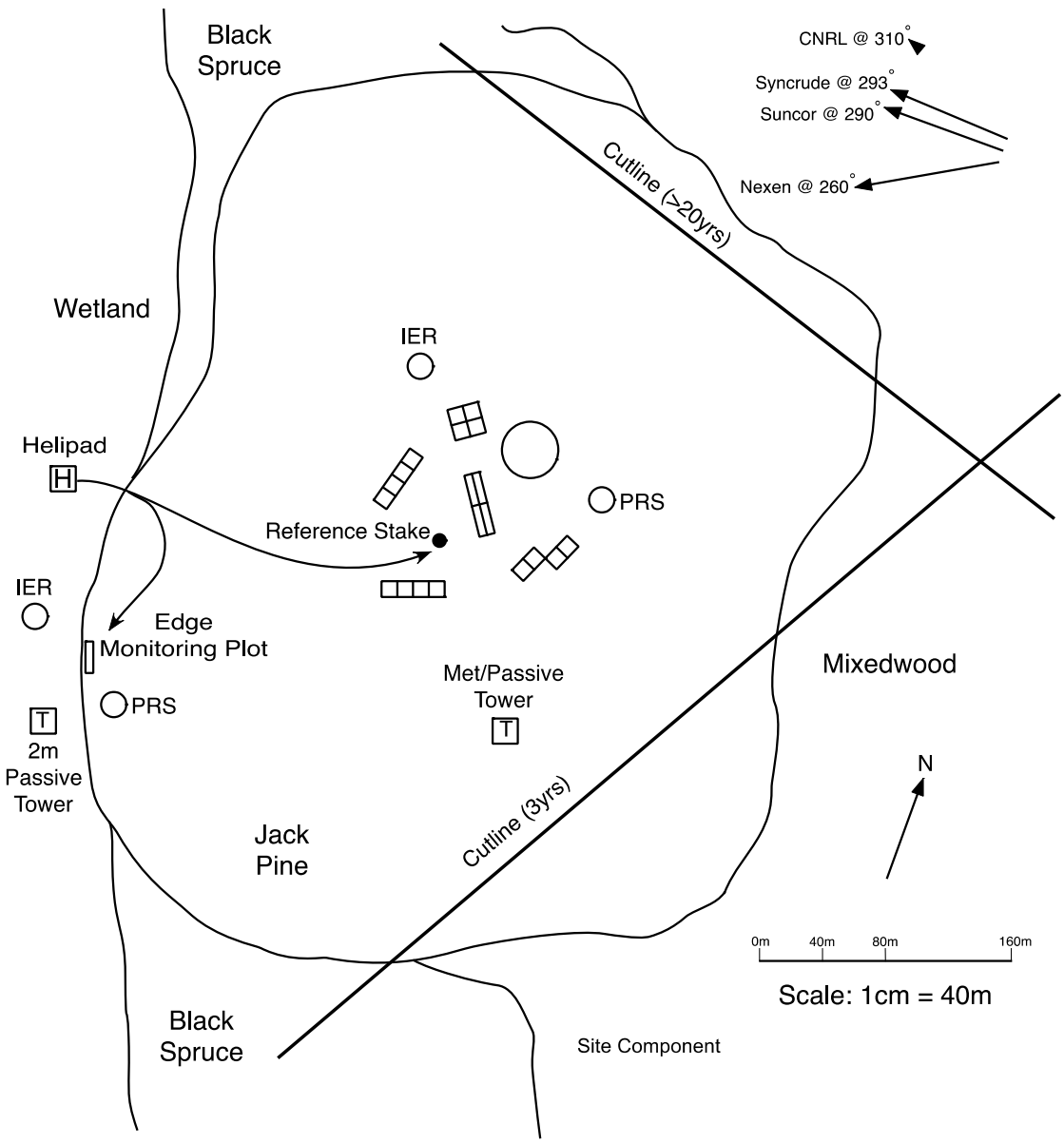


Figure 4.4: Example Site Drawing

(Syncrude, Suncor, CNRL, Nexen) are to be included. A table presenting the coordinates of important site features (reference stake, helicopter landing site, etc.) is also to be included on the drawing. An example of an acceptable site drawing is presented in Figure 4.4.

4.4 Interior Monitoring Site Information

Site information for a new vegetation plot is to be acquired according to the **SITE INFORMATION PROCEDURE (#3)**, which includes completion of TEEM Form 01. Practitioners should complete this form in detail, ensuring that a person who had not visited the site is able to visualize the

location of the plot on the terrain. Site information and observations should be from the perspective of the vegetation plot.

4.5 *Public Lands Act* Disposition Application

A *Public Lands Act* disposition for an environmental monitoring site is to be acquired from Alberta Environment and Sustainable Resource Development (AESRD). The type of disposition to be acquired will be determined in consultation with AESRD, as sites with a monitoring tower and/or monitoring instruments may require a different disposition type than a site with monitoring plots alone. Regardless of type, the disposition identifies for developers and other parties interested in the area that that a monitoring site is present. Developers are generally required to contact disposition holders (including WBEA) before entering into the area covered by the disposition, thus providing a level of protection against damage to the site.

At the conclusion of the site establishment program, an application for a disposition under the *Public Lands Act* is to be prepared, according to the ***PUBLIC LANDS* ACT DISPOSITIONS PROCEDURE (#6)**.

5.0 BASELINE SOIL DESCRIPTION

Baseline soil description and classification activities are part of the site establishment process, conducted in the summer, generally between mid-June and late August.

5.1 Soil Pit

In the year that the site is established, the soil at the site is to be classified on the basis of the soil exposed in, and samples taken from, a pit dug at least 1 m deep, preferably into the C horizon. The pit location (in decimal-degree format) is to be clearly noted on the site drawings.

The pit is to be a minimum of 10 m from the vegetation plot, no closer to any of the soil plots by at least 5 m. The location for the soil pit is to be determined during plot layout and staking (Section 4.3.3). The pit location should avoid obvious hummocks, depressions or other unique site characteristics. A soil pit approximately 1 m x 1 m is to be dug into the C horizon (or to 1 m deep if the C horizon is not encountered), placing excavated material on a plastic sheet or tarp on one side of the pit; this avoids contaminating the area around the pit. A larger pit is acceptable if the instability of sandy soils so requires.

At the completion of soil characterization and sampling, the soil pit is to be filled, with the upper horizon materials being replaced nearer the surface.

5.2 Baseline Soil Description

The soil exposed in the pit is to be described in sufficient detail that, together with the results of the laboratory analysis of pit samples, the soil can be classified into the appropriate subgroup of the Canadian System of Soil Classification (Soil Classification Working Group, 1998), and to the appropriate soil map unit. The soil pit information is acquired according to the **SOIL DESCRIPTION PROCEDURE (#7)**, which includes completion of TEEM Form 10.

5.3 Soil Pit Sample Collection

For soil classification, each **soil horizon** is to be measured, characterized, and samples taken for laboratory analysis. Sampling and measurement of soil horizons in the soil pit differs from the procedures for sampling during the 6-year, routine monitoring requirements, and practitioners must be fully aware of this critical difference.

5.3.1 LFH Sample Collection

Of the soil horizons, the LFH chemistry is impacted the greatest by air emissions and deposition, as it is composed of shed vegetative material that was directly exposed to emitted substances in the air, and as the uppermost layer of the soil column is the direct recipient of precipitation.

A sample of the LFH horizon is to be taken from a 2,500 cm^2 area (larger area if material is sparse) at the location of the soil pit, prior to beginning the excavation of the pit. A stainless steel knife, scraper or spoon is used to carefully loosen all litter material from the mineral soil,

and to add this loosened material to the sample. Mineral soil is to be excluded from the sample as much as possible.

A field duplicate sample of LFH material is to be obtained from 10% of the sites being established in a single year, rounded up to the next whole number (e.g., 1 field duplicate for up to 10 sites, 2 field duplicate samples for 11 to 20 sites; 3 for 21 to 30 sites, etc.). To collect a field duplicate, approximately twice the amount of LFH material (over an area of up to 5,000 cm^2) is to be collected. This material, once cleaned, is to be thoroughly mixed. The mixed sample is to be divided into two equal portions, one representing the subplot sample, the other the field duplicate.

Each cleaned LFH sample is to be placed into a labelled plastic zipper storage bag, which itself is to be placed into a second, labelled plastic zipper storage bag. Samples are to be labelled and handled according to the **SAMPLE LABELLING PROCEDURE (#1)** and the **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**.

5.3.2 Mineral Soil Sample Collection

Preparation of the pit sides for sampling, and the sampling itself, must be conducted with stainless steel hand tools. At least one side of the soil pit should be prepared for photography and sampling. If roots or other materials interfere with proper sampling, or the horizon is thin, material may be taken from the same horizon on the other pit side(s).

Prior to sampling, the pit wall is to be photographed. Photograph numbers are to be recorded in field notes.

Samples should be taken from the entire depth of each horizon. A volume of soil sufficient to provide a approximately 500 cm^3 of material for laboratory analyses (after removing coarse fragments) is to be taken. This will ensure that sufficient material is available for the suite of laboratory analyses required, and to archive sufficient remaining material to repeat laboratory analyses if required at a future date. Sampling is to begin at the bottom of the pit (C horizon) and proceed upwards to avoid contamination of lower soils during the sampling process. In the case of deep horizons, sample collection may be facilitated by scraping a larger than required amount of soil (ensuring that the entire depth of the horizon is equally sampled) onto a flat, clean surface, mixing completely and taking the 500 cm^3 sample from the mixed material.

A field duplicate sample of each mineral horizon is to be obtained from 10% of the sites (pits) being established in a single year, rounded up to the next whole number (1 field duplicate set for up to 10 sites, 2 field duplicate sets for 11 to 20 sites; 3 for 21 to 30 sites, etc.). To obtain a field duplicate sample from a soil pit, twice the amount of soil from a horizon is to be obtained from the pit and placed onto a clean surface. This sample is to be completely mixed and divided into two equal portions, one as the soil pit sample; the other as the soil pit duplicate sample.

Each mineral soil sample is to be placed into a plastic zipper storage bag, which itself is to be placed into a second, labelled plastic zipper storage bag. Samples are to be labelled and

handled according to the **SAMPLE LABELLING PROCEDURE (#1)** and the **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**.

5.4 Laboratory Analyses

5.4.1 Sample Preparation

Upon receipt at the laboratory, soil samples are to be split into two subsamples in an approximate 75:25 ratio. The larger of the samples is to be dried, while the smaller is to be returned to the fridge or freezer. The field moist subsamples are to be reserved for analysis of soluble nutrients.

Drying of soil samples is to be conducted according to the **SOIL SAMPLE PREPARATION & WEIGHING PROCEDURE (#9)**. Dried samples are to be passed through a 2 mm sieve; the dried LFH sample will require grinding to a particle size of 2 mm. As required for individual analyses, some soil samples require additional grinding to a finer (e.g., 100 mesh) particle size.

5.4.2 Texture

Soil texture (proportion of sand, silt and clay) is a measurement of the size distribution of the individual mineral particles in a soil sample. Soil texture data are used in soil classification, evaluation of field texture, quantification of clay movement in soil horizons, determination of the relationship of parent material to the soil, chemical adsorption properties, base exchange capacity, water retention, unsaturated hydraulic conductivity, permeability, aeration, and soil plasticity (Schumacher et al., 1995). Each mineral soil horizon sampled from the soil pit is to be analysed for soil texture according to the **SOIL TEXTURE ANALYSIS PROCEDURE (#10)**, which is based on Kalra and Maynard (1991) and Carter and Gregorich (2008).

Soil texture analysis is a part of the soil classification process, and this analysis is required only during the site establishment year.

5.4.3 pH

Soil pH is one of the most indicative chemical measurements in soil (Schumacher et al., 1995). Soil pH is a measure of the hydrogen ion activity in the soil solution and can, therefore, be considered as the intensity factor for soil acidity. Soil pH is integral to many other soil properties such as the solubility of compounds, the availability of plant nutrients, the relative bonding of ions to exchange sites, and the activity of soil microorganisms. Decreases in soil pH resulting from soil acidification may reflect an overall decline in base saturation and an increase in the exchangeable acidity (Bach, 1980).

A calcium chloride ($CaCl_2$) solution is to be used in the analysis of pH in soil samples from the Forest Health Monitoring Program (Kalra and Maynard, 1991). Data generated from analyses conducted using other solutions cannot be directly compared to data generated from the analysis of pH in $CaCl_2$ solutions.

Samples taken from the LFH horizon and each mineral soil horizon are to be analysed for soil pH. Litter and mineral soil samples used for this analysis are to be air-dried. The pH of a soil sample is measured according to the **SOIL PH ANALYSIS PROCEDURE (#11)**.

5.4.4 Electrical Conductivity

Soil salinity reduces plant growth via depression of the osmotic potential of the soil solution, which limits water uptake by vegetation (Corwin and Lesch, 2003). Salinity may also cause specific ion toxicity or nutrient imbalances. Soil salinity is to be assessed by measuring the electrical conductivity (EC) of a soil extract (Kalra and Maynard, 1991; Miller and Curtin, 2008). The main ions comprising soluble salts are cations (Na^+, Ca^{2+}, Mg^{2+}) and anions (SO_4^{2-} and Cl^-). Minor amounts of K^+, HCO_3^-, CO_3^-, and NO_3^- may also be present.

Analysis of electrical conductivity in soil samples is to be conducted according to the **SOIL ELECTRICAL CONDUCTIVITY ANALYSIS PROCEDURE (#12)**, which is based on Miller and Curtin, (2008).

5.4.5 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is a bulk surrogate for the presence and availability of plant nutrients (Schumacher et al., 1995). CEC, usually expressed in $cmol^+$/kg of soil, is a measurement of the quantity of readily exchangeable cations in the soil (Rhoades, 1982). These cations include Ca^{2+}, Mg^{2+}, Na^+, and K^+, critical nutrients for plant health. CEC is highly dependant on the quantity and character of the clay minerals present in the soil, and on soil pH. Decreases in soil pH will produce a related decrease in CEC. Analysis of soil cation exchange capacity is to be conducted according to the **SOIL CATION EXCHANGE CAPACITY ANALYSIS PROCEDURE (#13)**, which is based on Kalra and Maynard (1991) and Skinner et al. (2001).

5.4.6 Exchangeable Cations

The analysis of exchangeable cation concentrations provides the data necessary for the calculation of the BC:Al ratio and the base saturation percentage (BS%). This analysis is to be conducted according to the **SOIL EXCHANGEABLE CATIONS ANALYSIS PROCEDURE (#14).**

5.4.7 BC:Al Ratio

The ratio between base cations and aluminum in the soil is an important indicator for soil health. Soil base cations, Ca^{2+}, Mg^{2+}, and K^+, are important nutrients for plant growth, while Al^{3+} may be toxic to vegetation. Soil acidification and leaching process can lead to depletion of base cations and the release of adsorbed Al^{3+} into the soil water solution (Belyazid, 2005). This leads to a larger fraction of exchange sites being occupied by aluminum at the expense of Ca^{2+}, Mg^{2+}, and K^+, and ultimately to a decrease in the BC:Al ratio (Cronan and Grigal, 1995).

The BC:Al ratio is a calculated value, derived according to the **BC:AL CALCULATION PROCEDURE (#15)**.

5.4.8 Base Saturation

Base saturation (Ross et al., 2008) is the proportion of cation exchange sites in the soil occupied by plant nutrient cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}). Non-nutrient cations (H^{+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+}, Al^{3+}, and others) can also occupy cation exchange sites. Some of these cations, including Al^{3+}, are toxic to plants. A positive relationship between pH and base saturation has been postulated in models used to predict soil changes caused by acid deposition (Reuss, 1983; Reuss and Johnson, 1985; Robarge and Johnson, 1992). Base saturation is also often referenced in the forest soil literature as an indicator of the effects of acidic deposition or the recovery from these effects (Reuss, 1983).

The BS% is calculated according to the **SOIL BASE SATURATION PERCENTAGE CALCULATION PROCEDURE (#16)**.

5.4.9 Total Sulphur, Nitrogen & Carbon

Quantification of total carbon, in conjunction with total nitrogen and total sulphur, provides insight about the potential for uptake or release of nitrogen and/or sulphur by the soil organic matter due to microbial activity (Blume et al., 1980). Carbon, nitrogen, and sulphur cycle between organic and inorganic forms in the soil, soil microbes, and plant systems.

Carbon, nitrogen and sulphur dynamics may be altered in trees exposed to air emissions. Nitrogen and sulphur may accumulate in needles exposed to sulphur and nitrogen oxides, and ammonia. Carbon distribution may be altered in response to plant stress, including that caused by air contaminants. These changes may become apparent in soils as shed needles with altered carbon and/or nutrient content are deposited to the soil surface. The Forest Health Monitoring Program assesses soil total C, N and S to study the interaction of inputs of nitrogen and sulphur with the cycling of C, N, and S in the soil system.

Total carbon, nitrogen, and sulphur are measured using dry combustion (Skjemstad and Baldock, 2008), described in the **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

5.4.10 Carbon to Nitrogen Ratio (C:N)

Nitrogen can enter the soil as a component of acid deposition. High nitrogen deposition can lead also to nitrogen saturation, causing a variety of effects that vary by ecosystem type (Brady and Weil, 2008; Galloway et al., 2008; Millennium Ecosystem Assessment, 2005; Rockström et al, 2009) or dramatic increases in export of dissolved organic carbon and nitrogen from forest ecosystems to streams, rivers, lakes, and coastal systems (Pregitzer et al., 2004). If the balance between carbon and nitrogen in the soil is heavily weighted towards carbon, the decomposition of organic material in the soil by fungi and bacteria will deplete soil nitrogen. If the balance is heavily weighted towards nitrogen, the decomposition of organic material in the soil by fungi and bacteria will be unable to consume all available nitrogen leading to a build up of nitrogen. Deficiency or super-abundance of nitrogen in the soil may impair plant growth.

The carbon to nitrogen ratio (C:N) is calculated according to the **SOIL C:N CALCULATION PROCEDURE (#18)**.

5.4.11 Complexed Aluminum & Iron

Micronutrient chemistry in the terrestrial environment largely involves complexation reactions with organic substances (Schumacher et al., 1995). Much research has involved the isolation of soil humic substances and their associated micronutrients, particularly Fe and Al. Humic and fulvic acids are able to form stable complexes with metal ions as a result of their high levels of oxygen-containing functional groups. Organic Fe and Al complexes accumulate in the mineral horizons of certain types of soils and can be used to distinguish podzolic (spodic) B horizons. Micronutrient cations in displaced soil solutions have been found to occur partly in organically bound forms (Geering et al., 1969). With mounting evidence to demonstrate higher aluminum solubility with watershed acidification, the proportion of Fe and Al bound by organics may be important information in terrestrial monitoring programs assessing the impacts of atmospheric pollutants.

Through various extraction procedures, an approximate differentiation can be made between organic Fe and Al and other secondary accumulation products, such as Fe and Al oxides. A separate extraction to remove organic Fe and Al is required before the oxide fraction can be isolated. This distinction may be of particular importance in terrestrial studies impacts of atmospheric pollutants where amorphous and finely divided crystalline oxide fraction has been shown to largely control SO_4^{2-} adsorption (Chao et al., 1962; Rajan, 1978; Neary et al., 1987). In turn, soil cation leaching can be controlled by SO_4^{2} adsorption (Huete and McColl, 1984). Organic matter has been found by some researchers to have a negative influence on SO_4^{2-} adsorption (Johnson and Todd, 1983).

The pyrophosphate extraction procedure assesses organically bound iron and aluminum in soil. The dithionate extraction procedure provides a bulk assessment of both the organically bound and inorganic (oxide) forms of iron and aluminum in soil. The Forest Health Monitoring Program assesses both organically bound iron and aluminum (through pyrophosphate extraction) and oxide forms of iron and aluminum (through dithionate extraction and comparison with the results of the extraction using pyrophosphate) in the soil classification process. Since this is expected to be a relatively stable parameter, this measurement need only be done initially as a component of the soil characterization program during site establishment. The results of these analyses are used in the classification of soils, predominantly the differentiation between Podzols and Brunisols.

This extraction and analysis is based on Courchesne and Tunnel (2008), and is to be conducted according to the **SOIL COMPLEXED ALUMINUM & IRON ANALYSIS PROCEDURE (#19)**.

6.0 BASELINE VEGETATION DESCRIPTION

Following the layout and staking of the vegetation plot, a number of measurements of plot and off-plot trees are to be taken, and samples from off-plot trees are to be acquired. These data comprise the baseline data, against which data collected in future years will be compared. To ensure consistent data collection across plots and from year to year, TEEM data forms are to be used; no other forms are acceptable.

Baseline vegetation description activities are to be conducted between mid-June and mid-September. These activites are generally conducted concurrently with the measurements and sampling associated with the routine (6-year) monitoring program (Section 8).

6.1 Labelling & Marking Vegetation Plot Trees

Within the vegetation plot, all standing trees (living and dead) of 10 cm DBH and larger, except for dead standing trees whose tops do not reach into the canopy, are to be numbered and labelled according to the **TREE NUMBERING & LABELLING PROCEDURE (#5)**.

A tree is deemed to be within the vegetation plot if its point of germination occurred in the plot, thus, trees that germinated within the plot, but which lean outside the plot are considered to be in the plot. Conversely, trees that germinated outside the plot but which lean into the plot are to be excluded. Trees that fork at a height of 1.3 m or lower are considered to be two trees, and each stem is to be separately numbered and tagged. Trees that grow in clumps (rare for jack pine) having germinated from the same location are deemed to be plot trees if the germination point is in the plot – all stems in the clump having reached 10 cm DBH are to be separately numbered and tagged.

6.2 Vegetation Plot Tree Map

The vegetation plot map identifies individual trees within the plot, such that observation and measurement data can be collected for specific, known trees. These data are used to track tree growth, health and decadence over the period of the monitoring program.

Trees are to be mapped within the four quadrants of the vegetation plot, as assigned during plot staking (Section 4.3.1), according to the **TREE MAPPING MEASUREMENTS PROCEDURE (#24)**, which includes completion of TEEM Form 02. From these measurements, a scale map of the plot is to be generated. The plot map is to include an arrow to true North, the bearing of the Reference Line, and arrows showing the direction and bearing to the Suncor, Syncrude, CNRL and Nexen oil sands processing facilities. An example vegetation plot map is shown in Figure 6.1.

6.3 Off-Plot Tree Age

The effects of air emissions and deposition on the growth and health of jack pine trees are expected to be observable on trees 50 to 70 years of age. This period represents the maturation stage of growth – after rapid growth and before the onset of decadence and death.

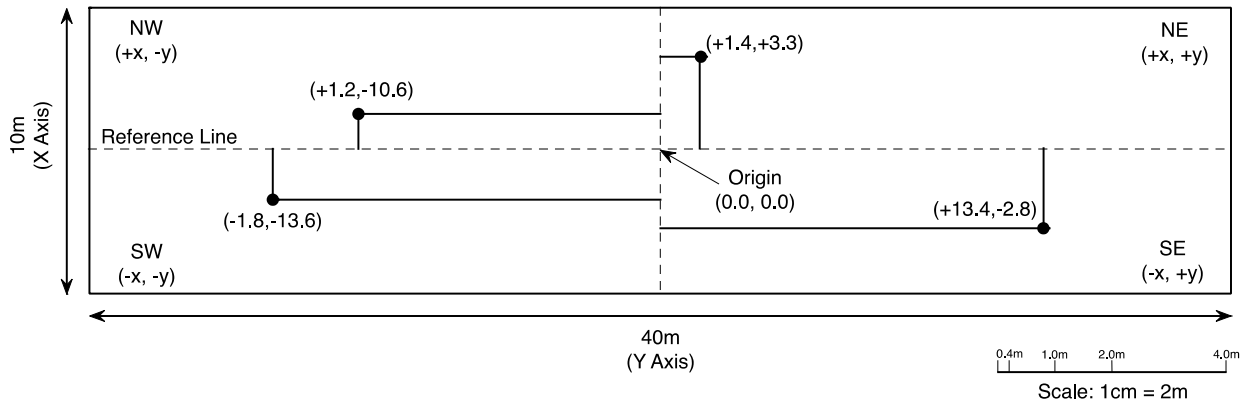


Figure 6.1: Example Tree Plot Map

Tree cores are to be obtained using **TREE CORING PROCEDURE (#25)**. Tree cores are to be processed and analysed according to the **TREE CORE PREPARATION & ANALYSIS PROCEDURE (#26)**, which includes completion of TEEM Form X05.

7.0 ANNUAL PROGRAMS

7.1 Annual Forest Health Assessment

In the early stages of the Forest Health Monitoring Program, an assessment of the health of each of the jack pine (AMEC Earth & Environmental Limited, 2000a, b, 2002a, 2003) and aspen monitoring sites was conducted annually. The purposes of this annual assessment program were to identify and record the overall disease, insect and mechanical damage within a plot, recent tree mortality and the cause of death, the general forest health in proximity to the monitoring plots, and changes in forest health since the last assessment. These data were supportive of the understanding of stresses and their causes that may be observed or quantitatively measured during the more intensive measurements made on the 6-year monitoring cycle.

In 2011, a program of annual evaluation of the health of the forests at each Forest Health Monitoring Program site was re-initiated. The objective of the annual assessment is to obtain data on forest health that will support interpretations of the measurement and sample analysis data acquired every six years.

The forest health assessment is to be completed between August 1 and September 15 in each year. A minimum of two hours is to be dedicated to the examination of trees, identification of stress symptoms, and identification of the causal agent at each site. Most of this time is to be dedicated to the assessment of vegetation plot and off-plot trees, with the remainder to be spent examining the overall site. An experienced forest specialist is to conduct the assessment.

Each of the vegetation plot and numbered off-plot trees are to be examined in detail, using binoculars to scan the tree crowns, according to the **TREE CONDITION & HEALTH ASSESSMENT PROCEDURE (#27)**, which includes completion of TEEM Forms 04 (vegetation plot), X04 (off-plot trees) and E04 (edge monitoring plot trees).

7.2 Annual Plot Maintenance

Maintenance of each site is required to ensure that plot stakes and tree labels continue to be easily read and that equipment is operating as desired. Absence of maintenance may introduce variability into the program, potentially leading to samples and/or measurements being taken in an incorrect place.

A maintenance crew is to examine all monitoring and investigative program components at each site, performing maintenance as required. This is to include:

- maintaining the helicopter landing pad and trail to the monitoring site;
- inspecting and replacing the reference stake, as necessary;
- restoring or replacing plot stakes; and
- examining and restoring as necessary tree markings and labels.

The maintenance crew is to also conduct a visual inspection of the trees at the site, and of the surrounding area, and record their observations in field note format. Items to record include but are not limited to:

- signs of physical damage and/or biological stresses within the site (e.g., wildlife, wind damage, insect infestation, drought); and
- signs of physical damage outside of the site boundaries (e.g., wind damage, resource exploration), and/or biological stresses outside of the site.

Crews are encouraged to prepare detailed notes recording site observations, as these notes may be important in the interpretation of biophysical data acquired during the sampling and measurement programs. Maintenance activities at each site are to be recorded. Observations and site maintenance reports are to be submitted to the TEEM Program Manager at the end of each field day.

This maintenance may be combined with a scheduled site visit for other activities (monitoring, air quality passive sampler replacement, deposition resin replacement, etc.). However, sufficient time must be available to complete all maintenance activities in one trip.

8.0 SOIL MONITORING PROGRAM (6-YEAR CYCLE)

Routine soil monitoring procedures apply to the year of plot establishment and in every subsequent year during which samples are collected as part of the routine monitoring program (at present, soil monitoring is on a 6-year cycle).

Within each 10 m x 10 m soil subplot, nine sample locations are to be defined. Plots of smaller dimensions (i.e., 30 m x 10 m and 30 m x 7.5 m) are to contain six sample locations per subplot. These sampling locations are fixed points (Figure 8.1), however, they are not to be marked in the field.

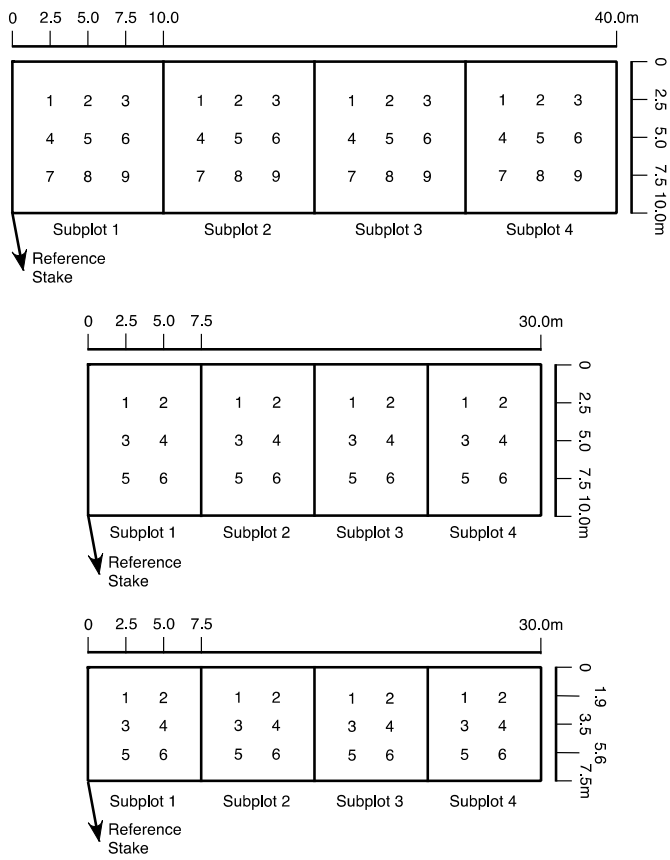


Figure 8.1: Soil Sample Locations within each Soil Subplot, within a Single Soil Plot (acceptable plot sizes shown)

In each routine sampling year, one of the sample locations in each of the four soil subplots in each soil plot is to be sampled. Sample locations are to be selected using a random number generator, in advance of the field program. A single number, from 1 to 9 (1 to 6 for the smaller subplots) is to be selected for each subplot. The point within the subplot represented by the chosen number defines the location in the subplot at which the soil sample is to be taken. Because of the destructive nature of soil sampling, a location is to be used only once. If in subsequent years a previously sampled location is randomly selected, the random number is to be discarded and another chosen. This process is to be repeated until a sample point within

each subplot, in all soil plots at all sites has been identified. The sample points chosen by this process are to be recorded on TEEM Form 11, as described in the **SOIL SAMPLE LOCATION & CHECKLIST PROCEDURE (#8)**.

To determine the location from which a field duplicate sample is to be taken, a random number from 1 to 4 is to be chosen (to identify the soil plot), followed by the selection of a second random number from 1 to 4 (to identify the soil subplot within the selected plot). The location from which the field duplicate samples are to be taken is to be recorded on TEEM Form 11 (**SOIL SAMPLE LOCATION & CHECKLIST PROCEDURE (#8)**).

If a tree at or near the sample points interferes with proper sampling, the sampling point is to move the minimum distance required to a location where the interference ceases to occur. The direction of movement of a sample location is shown in Figure 8.2. Adjustments to soil sampling locations are to be measured, to the nearest 0.1 m, and recorded on TEEM Form 11 (**SOIL SAMPLE LOCATION & CHECKLIST PROCEDURE (#8)**).

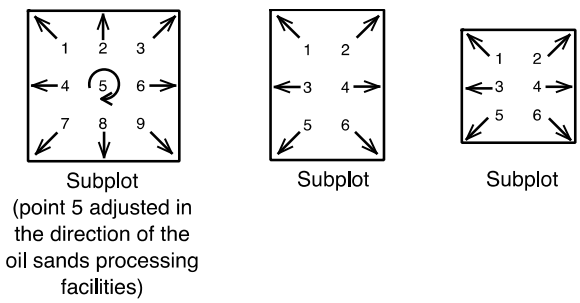


Figure 8.2: Soil Subplot Sampling Adjustments

8.1 Sample Collection

In routine soil sampling and monitoring, samples are collected by **depth** (except for the LFH horizon), which differs from the sampling by horizon conducted for baseline soil characterization using the soil pit. Practitioners must understand this critical requirement of the program.

All soil sampling is to be conducted using stainless steel tools, and while wearing nitrile, powderless gloves.

8.1.1 LFH Sample Collection

LFH chemistry is impacted the greatest by air emissions and deposition, as it is composed of shed vegetative material that was directly exposed to emitted substances in the air, and as the uppermost layer of the soil column is the direct recipient of precipitation.

An LFH sample is to be collected from the randomly selected, pre-determined location within each soil subplot. Using a stainless steel hand tool (e.g., scraper, spade, knife, spoon), the entire LFH layer is to be carefully removed from an area of about 2,500 cm^2 (larger area if

material is sparse) at the sample location. Mineral soil is to be excluded from the sample as much as possible.

A field duplicate LFH sample is to be collected from one randomly chosen subplot, within one randomly chosen plot, at each site. From this location, approximately twice the amount of LFH material (over an area of up to 5,000 cm^2) is to be collected. This material, once cleaned, is to be placed on a clean surface, and thoroughly mixed. The mixed sample is to be divided into two equal portions, one representing the subplot sample, the other the field duplicate. One is to be bagged and labelled as the subplot sample; the other is to be bagged and labelled as the field duplicate.

Each cleaned LFH sample is to be placed into a labelled plastic zipper storage bag, which itself is to be placed into a second, labelled plastic zipper storage bag. Samples are to be labelled according to the **SAMPLE LABELLING PROCEDURE (#1)**, and stored/shipped according to **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**.

8.1.2 Mineral Soil Sample Collection

Samples of each of the 0 to 5 cm, 5 to 15 cm, and 15 to 30 cm mineral soil layers are to be obtained from each subplot sample location, from each soil plot at each site, during each sample cycle. In the year of site establishment, a sample of the 30 to 50 cm layer is also to be obtained from each sample location.

In the area cleared of LFH material, a plug of soil to a depth of about 40 cm (routine monitoring year) or 60 cm (site establishment year) is to be removed using a spade. The dimensions of the plug are determined by the width of the spade (generally 20 cm). Samples of soil are to be taken from the plug in 0 to 5 cm, 5 to 15 cm, 15 to 30 cm (in all years), and 30 to 50 cm depths (site establishment year only[1]). Approximately 500 cm^3 of soil is required from each depth; this should be viewed as a minimum requirement.

A field duplicate sample from each soil layer is to be collected from the same location as was used for the collection of the field duplicate LFH sample. From this location, approximately twice the amount of mineral soil material (1,000 cm^3) is to be collected. This material is to be placed on a clean surface, and thoroughly mixed. The mixed sample is to be divided into two equal portions: one as the subplot sample, the other as the field duplicate.

Each sample is to be placed into a labelled plastic zipper storage bag, which itself is to be placed into a second, labelled plastic zipper storage bag. Samples are to be labelled according to the **SAMPLE LABELLING PROCEDURE (#1)**, and stored/shipped according to **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**.

[1] If changes in soil chemistry become apparent in the shallower depth samples, the TEEM committee may elect to add sampling of the 30 to 50 cm depth increment to the routine monitoring cycle

8.2 Laboratory Analyses

Standardization of the laboratory component of the program is required to ensure that the results allow comparison across sites and over years. For some analyses, only one procedure is available, making standardization relatively simple. For others, however, several procedures may be available, and it is critical that the procedure required by the TEEM program be used, unless changes have been approved in advance by the TEEM Program Manager.

Because of the number of samples acquired, the need for specific analyses, and the schedule by which the laboratory results will be required, selection of a laboratory (or laboratories) should be made well in advance of the field program. The selected laboratory(ies) should be made aware of all analyses required, again well in advance of the field program, such that when the samples arrive laboratory staff are prepared to properly receive them and initiate the analyses or place the samples in appropriate storage. Field staff must also explicitly request the required analysis (or analyses) on the chain-of-custody form(s). This is a confirmatory step; should the request on the chain-of-custody form not match that expected by the laboratory, a discussion among the laboratory, field team members, project manager and/or TEEM Program Manager should occur so that the proper analysis (analyses) are completed by the laboratory.

8.2.1 pH

Soil pH is one of the most indicative chemical measurements in soil (Schumacher et al., 1995). Soil pH is a measure of the hydrogen ion activity in the soil solution and can, therefore, be considered as the intensity factor for soil acidity. Soil pH is integral to many other soil properties such as the solubility of compounds, the availability of plant nutrients, the relative bonding of ions to exchange sites, and the activity of soil microorganisms. Decreases in soil pH resulting from soil acidification may reflect an overall decline in base saturation and an increase in the exchangeable acidity (Bach, 1980). The Forest Health Monitoring Program includes soil pH analyses to identify and track changes to soil acidity. Decreases in soil pH resulting from soil acidification may reflect an overall decline in base saturation and an increase in the exchangeable acidity (Bach, 1980).

Samples taken from the LFH horizon and each mineral soil layer (by depth) are to be analysed for soil pH, using a $CaCl_2$ solution (Kalra and Maynard, 1991), as described in the **SOIL PH ANALYSIS PROCEDURE (#11)**.

8.2.2 Soluble Ions

The ions that are dissolved in soil solution are available for plant and microbe uptake. Changes in the concentration of soluble ions may have a direct effect on microbial activity, plant root uptake, or both. The concentrations of ions in soil solution represent the pool of ions available to plants through root uptake. The analysis of soluble ions in a soil sample is to be conducted according to the **SOIL SOLUBLE CATIONS ANALYSIS PROCEDURE (#20)**.

8.2.3 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is a bulk surrogate for the presence and availability of plant nutrients (Schumacher et al., 1995). CEC, usually expressed in $cmol^+$/kg of soil, is a measurement of the quantity of readily exchangeable cations in the soil (Rhoades, 1982). These cations include Ca^{2+}, Mg^{2+}, Na^+, and K^+, critical nutrients for plant health. CEC is highly dependant on the quantity and character of the clay minerals present in the soil, and on soil pH. Decreases in soil pH will produce a related decrease in CEC. Analysis of soil cation exchange capacity is to be conducted according to the **SOIL CATION EXCHANGE CAPACITY ANALYSIS PROCEDURE (#13)**.

8.2.4 Exchangeable Cations

The analysis of exchangeable cation concentrations provides the necessary data for the calculation of the BC:Al ratio and the base saturation percentage (BS%). This analysis is to be conducted according to the **SOIL EXCHANGEABLE CATIONS ANALYSIS PROCEDURE (#14)**.

8.2.5 BC:Al Ratio

The ratio between base cations and aluminum in the soil is an important indicator for soil health. Soil base cations, Ca^{2+}, Mg^{2+}, and K^+, are important nutrients for plant growth, while Al^{3+} may be toxic to vegetation. Soil acidification and leaching process can lead to depletion of base cations and the release of adsorbed Al^{3+} into the soil water solution (Belyazid, 2005). This leads to a larger fraction of exchange sites being occupied by aluminum at the expense of Ca^{2+}, Mg^{2+}, and K^+, and ultimately to a decrease in the BC:Al ratio (Cronan and Grigal, 1995).

The Acid Deposition Management Framework (Cumulative Environmental Management Association, 2004), a regional environmental management instrument implemented by Alberta Environment, includes the BC:Al ratio as an indicator of soil acidification. Reductions in the ratio value below thresholds in the ADMF will initiate management responses. Monitoring of the BC:Al in the region is required; the analysis of BC:Al in sensitive soils in the Forest Health Monitoring Program fulfills this requirement.

The BC:Al ratio is a calculated value, derived according to the **SOIL BC:AL CALCULATION PROCEDURE (#15)**.

8.2.6 Base Saturation

Base saturation (Ross et al., 2008) is the proportion of cation exchange sites in the soil occupied by plant nutrient cations (Ca^{2+}, Mg^{2+}, K^+, Na^+). Non-nutrient cations (H^+, Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+}, Al^{3+}, and others) can also occupy cation exchange sites. Some of these cations, including Al^{3+}, are toxic to plants. A positive relationship between pH and base saturation has been postulated in models used to predict soil changes caused by acid deposition (Reuss, 1983; Reuss and Johnson, 1985; Robarge and Johnson, 1992). Base saturation is also often referenced in the forest soil literature as an indicator of the effects of acidic deposition or the recovery from these effects (Reuss, 1983).

The Acid Deposition Management Framework (Cumulative Environmental Management Association, 2004), a regional environmental management instrument implemented by Alberta Environment, includes the BS% as an indicator of soil acidification. Reductions in BS% below thresholds in the framework will initiate management responses. Monitoring of BS% in the region is required; the analysis of BS% in sensitive soils in the Forest Health Monitoring Program fulfills this requirement.

The BS% is calculated according to the **SOIL BASE SATURATION PERCENTAGE CALCULATION PROCEDURE (#16)**.

8.2.7 Total Sulphur, Nitrogen & Sulphur

Quantification of total carbon, in conjunction with total nitrogen and total sulphur, provides insight about the potential for uptake or release of nitrogen and/or sulphur by the soil organic matter due to microbial activity (Blume et al., 1990). Carbon, nitrogen, and sulphur cycle between organic and inorganic forms in the soil, soil microbes, and plant systems.

Carbon, nitrogen and sulphur dynamics may be altered in trees exposed to air emissions. Nitrogen and sulphur may accumulate in needles exposed to sulphur and nitrogen oxides, and ammonia. Carbon distribution may be altered in response to plant stress, including that caused by air contaminants. These changes may become apparent in soils as shed needles with altered carbon and/or nutrient content are deposited to the soil surface. The Forest Health Monitoring Program assesses soil total C, N and S to study the interaction of inputs of nitrogen and sulphur with the cycling of C, N, and S in the soil system.

Total carbon, nitrogen, and sulphur are measured using dry combustion (Skjemstad and Baldock, 2008), described in the **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

8.2.8 Carbon to Nitrogen Ratio (C:N)

Nitrogen can enter the soil as a component of acid deposition. High nitrogen deposition can lead also to nitrogen saturation, causing a variety of effects that vary by ecosystem type (Brady and Weil, 2008; Galloway et al., 2008; Millennium Ecosystem Assessment, 2005; Rockström et al, 2009) or dramatic increases in export of dissolved organic carbon and nitrogen from forest ecosystems to streams, rivers, lakes, and coastal systems (Pregitzer et al., 2004). If the balance between carbon and nitrogen in the soil is heavily weighted towards carbon, decomposition of organic material in the soil by fungi and bacteria will deplete soil nitrogen. If the balance between carbon and nitrogen in the soil is heavily weighted towards nitrogen, the fungi and bacteria will be unable to consume all available nitrogen leading to a build up of nitrogen. Deficiency or super-abundance of nitrogen in the soil may impair plant growth.

The Forest Health Monitoring Program includes analyses of the C:N ratio in soil samples obtained from the jack pine sites to identify and track changes in the balance between soil carbon and nitrogen that may be related to exposure and deposition to nitrogen and sulphur compounds. The Cumulative Environmental Management Association (2008) identified the C:N

ratio as a potential marker of nitrogen accumulation forest soils, and recommended that the TEEM Forest Health Monitoring Program continue to conduct the analyses required to derive the C:N ratio in forest litter at each monitoring site.

The carbon to nitrogen ratio (C:N) is calculated according to the **SOIL C:N CALCULATION PROCEDURE (#18)**.

8.2.9 Soluble Nitrogen

High nitrogen deposition can lead to acidification and/or nitrogen saturation, causing a variety of effects that vary by ecosystem type (Galloway et al., 2008; Millennium Ecosystem Assessment, 2005; Rockström et al, 2009) or dramatic increases in export of dissolved organic carbon and nitrogen from forest ecosystems to streams, rivers, lakes, and coastal systems (Pregitzer et al., 2004). The majority of nitrogen in the soil that is available to plants as nitrate (NO_3^-) and ammonium (NH_4^+). Nitrate (NO_3^-) and ammonium (NH_4^+) levels in soil are to be determined according to the **SOIL SOLUBLE NITROGEN ANALYSIS PROCEDURE (#21)**, which is based on the methods described in Carter and Gregorich (2008) and Kalra and Maynard (1991).

8.2.10 Soluble Phosphorus

Phosphorus (P) is an essential nutrient for plant growth and is required in relatively large quantities by plants (Schumacher et al., 1995). It is essential for energy transfer reactions within all cells and is a constituent of many proteins, nucleic acids, and coenzymes. The availability of P to plants is influenced by soil pH, being most available to plants at a soil pH of 6 to 7. At pH lower than 6, P becomes fixed in iron and aluminum compounds, and, at pH above 7, calcium phosphates precipitate to an extent that may limit P availability.

Soluble phosphorus in soil samples is to be determined according to the **SOIL SOLUBLE PHOSPHORUS ANALYSIS PROCEDURE (#22)**, based on the Bray P-1 procedure as described in United States Department of Agriculture (2004), which is based on Bray and Kurtz (1945), Olsen and Sommers (1982) and Kuo (1996).

8.2.11 Inorganic Sulphur (S_i)

Sulphur, in the form of sulphate (SO_4^{2-}), is a principal anion in acid deposition (Schumacher et al., 1995), and SO_4^{2-} is generally the primary form of inorganic sulphur (S_i) found in mineral soils. In contrast, in organic horizons up to 50% of the total extractable S may be organically bound (S_o) (Maynard et al., 1987). The ability of soils to adsorb sulphate is one of the principal factors affecting the rate and extent of soil and watershed response to acidic deposition.

The Forest Health Monitoring Program includes analyses for inorganic sulphur (S_i) in soil samples from jack pine monitoring sites to identify and track changes to this key component of acid deposition. The analytical procedures for LFH (Kalra and Maynard, 1991) and mineral soil (Kalra and Maynard, 1991) samples differ; these are described in the **SOIL INORGANIC SULPHUR (S_i) ANALYSIS PROCEDURE (#23)**.

9.0 VEGETATION MONITORING PROGRAM (6-YEAR CYCLE)

Vegetation measurement, sampling and laboratory analysis procedures in the 6-year monitoring cycle apply in the year of plot establishment, and in every subsequent cycle. When conducted in the year of site establishment, routine vegetation monitoring procedures are to be initiated after the completion of site establishment procedures.

Routine vegetation monitoring activities are to be conducted between August 1 and September 15. Conducting all activities in this period allows for completion of current annual growth (CAG), while reducing the potential for physiological responses to the onset of autumn conditions (night frost).

9.1 Vegetation Plot Measurements & Assessments

9.1.1 Vegetation Plot Tree Data

Morphometric data are collected from each numbered tree within the vegetation plot during each monitoring cycle. These data allow for the evaluation and tracking of tree growth and health through the duration of the Forest Health Monitoring Program. Data are to be collected according to the **TREE DATA PROCEDURE (#28)**, which includes completion of TEEM Form 03.

9.1.2 Plant Community Assessment

Changes in soil chemistry and subsequent changes in vegetation growth and health may result in changes to the relative competitive ability of species currently growing at the jack pine monitoring sites. Altered competitive abilities may lead to changes in species composition, an ultimate outcome of atmospheric deposition of industrial emissions.

In 2004, an understory plant composition component was initiated at each of the jack pine sites in the program. The percent cover of vascular and non-vascular (mosses, liverworts, lichens) in each of 10 small, two medium and one large subplots within the vegetation plot were estimated. As these subplots have been permanently established, future assessments of percent cover of each species may provide an indication of community composition changes relating to the exposure to and/or deposition of industrial emissions.

Canopy cover, frequency of occurrence, and composition by canopy cover are to be evaluated for the ground cover and forb species within each of the 10 small, two medium and the large subplots using the Daubenmire (1959; Coulloudon et al., 1996) method of cover class estimation, as described in the **PLANT COMMUNITY ASSESSMENT PROCEDURE (#38)**. Data are to be entered into TEEM Form 08, and once complete, relevant data from TEEM Form 08 are to be transferred to TEEM Form 09 (Daubenmire Summary). TEEM Form 09 includes pre-programmed equations for the calculation of Total Canopy, Canopy Cover (%), contribution of each species to overall Species Composition (%), and Frequency (%) of occurrence of each species.

In addition to the quantitative cover data collected within each of the vegetation subplots, a “standard random walk” through the site is to be conducted according to the **PLANT COMMUNITY ASSESSMENT PROCEDURE (#38)**, to identify the presence of species not identified within the

subplots. This is a presence/absence survey only; quantitative cover or abundance data are not required.

9.2 Off-Plot Tree Measurement & Sampling

The use of off-plot trees that are morphologically and physiologically similar to the trees within the vegetation plot permits destructive sampling, measurement of crown growth, examination of branch and needle growth and condition, and sampling and analysis of foliar tissues, without affecting the health and condition of trees in the marked vegetation plot.

9.2.1 Examination & Replacement of Off-Plot Trees

In the event that an off-plot tree has died since the previous sampling cycle, or has been damaged or infected to the extent that it substantially differs from the rest of the trees at the site, it is to be replaced prior to conducting the visual assessment and sampling of off-plot trees. In particular, the crown of off-plot trees used for destructive sampling in two or more previous monitoring cycles must remain representative of the crowns of the trees in the stand as a whole.

In the event that one or more off-plot trees are no longer representative of the stand as a whole, a new tree or trees is(are) to be selected. These trees are to be numbered and labelled according to **TREE NUMBERING & LABELLING PROCEDURE (#5)**. The numbered tags are not to be removed from numbered trees that no longer meet the criteria for the program, however, the number painted on the tree should remain and be maintained. Records of trees removed from the program are required to ensure that a rejected tree does not re-enter the pool of off-plot trees at a later date.

9.2.2 Aging Replacement Off-Plot Trees

The aging of the replacement off-plot tree(s) during a routine monitoring event confirms that the replacement tree is of an age consistent with that of the other trees at the site. Tree cores are to be obtained using **TREE CORING PROCEDURE (#25)**. Tree cores are to be processed and analysed according to the **TREE CORE PREPARATION & ANALYSIS PROCEDURE (#26)**, which includes completion of TEEM Form X05.

9.2.3 Off-Plot Tree Data

Morphometric tree data are to be collected from each of the 10 off-plot trees. These data allow for a comparison between the plot and off-plot trees in terms of growth, ensuring that any divergence between the two populations is noted. Substantial divergence may require replacing some or all of the off-plot trees in future cycles. During the measurement process, tree tags, tree numbering, and DBH reference marks are to be checked and as required, repaired, refreshed or replaced.

Morphometric data are collected from each of the 10 numbered off-plot trees according to the **TREE DATA PROCEDURE (#28)**, which includes completion of TEEM Form X03.

9.2.4 Off-Plot Tree Condition & Health Assessment

An assessment of the health and condition of each of the 10 off-plot trees is to be conducted, prior to the excision of branches for detailed examination of branches and sampling of needles. This data collection procedure mirrors that conducted for trees in the vegetation plot, allowing for a comparison between the plot and off-plot trees in terms of health, ensuring that any divergence between the two populations is noted. Substantial divergence may require replacing some or all of the off-plot trees in future cycles. This condition and health assessment of off-plot trees has been a component of the Forest Health Monitoring Program from its inception.

The assessment of off-plot trees follows the **TREE CONDITION & HEALTH ASSESSMENT PROCEDURE (#27)**, which includes completion of TEEM Form X04.

9.3 Off-Plot Tree Needle Retention, Condition, Sampling & Analysis

9.3.1 Selection of Off-Plot Trees for Sampling

Selection of five trees at random from the pool of 10 for sampling each cycle will spread the damage caused by destructive sampling among the off-plot 10 trees, reducing the frequency at which off-plot trees will have to be replaced as a result of destructive sampling.

Six numbers from 1 to 10 are to be randomly selected in advance of the field program, and at each site the five trees represented by the first of the five selected numbers are to be sampled. A maximum of three branches are to be cut from any one tree. In the event that all three cut branches hang up in the canopy, the tree is to be left alone, and the sixth randomly chosen tree is to be used to acquire the necessary sample. This is illustrated in Table 7.1 for three fictitious jack pine monitoring sites, at which a different number of off-plot trees has been replaced at two of the sites during the monitoring program. Note that only one set of random numbers is required in each sampling cycle, and that this set applies to all jack pine monitoring sites for that year.

Table 7.1: Illustration of the Use of Random Numbers to Select Off-Plot Trees for Branch Excision and Foliar Sampling

Site*	Available Off-Plot Trees	Random Numbers	Off-Plot Trees to be Sampled
JP001	X001, X002, X004, X005, X006, X009, X010, X011, X012, and X013	1, 3, 4, 6, and 10 (2)**	X001, X004, X005, X009, and X013 (X002)**
JP002	X001, X002, X003, X004, X005, X006, X007, X008, X009, and X010		X001, X003, X004, X006, and X010 (X002)**
JP003	X003, X004, X005, X006, X010, X014, X015, X016, X019, and X021		X003, X005, X006, X014, and X021 (X004)**

* Site designations are fictitious and are for illustrative purposes, and do not relate to any jack pine monitoring sites in the Forest Health Monitoring Program.
** Number in parentheses is the sixth number, representing the reserve tree from which a branch is to be excised, should three cut branches from one of the five selected trees hang up in the canopy.

The random numbers are to be entered into TEEM Form X06 (**TREE SHOOT DATA PROCEDURE (#29)**).

9.3.2 Branch Excision

Needle sampling is to be conducted between August 1 and September 15. Current annual growth (CAG) will be complete or nearly so, physiological responses to the onset of autumn conditions (night frost) will be minimal, and the extent and magnitude of insect or pathogenic microorganisms will be less than expected later in the year.

A branch from each of the five selected off-plot trees is to be obtained from the upper third of the canopy, on the side of the tree facing the oil sands processing facilities. The branch is to be cut from the tree as close to the trunk as safely possible, using a pole pruner.

Cut branches may hang up in the canopy. Within the limits of safety associated with the pole pruner, gentle attempts to dislodge the branch may be made. If a branch cannot be dislodged, another branch is to be selected and cut. A maximum of three branches are to be cut from any one tree. In the event that all three cut branches hang up in the canopy, the tree is to be left alone, and the sixth randomly chosen tree is to be used to acquire the necessary sample.

9.3.3 Internode Length & Defoliation Estimate

The length of each internode on the each of the five main branches is to be measured and defoliation estimated according to the **TREE SHOOT DATA PROCEDURE (#29)**, which includes completion of TEEM Form X06.

9.3.4 Foliar (Needle) Sample Collection

Two separate sample types are to be collected for chemical analyses. One, termed “routine”, encompasses the suite of analyses that are typically conducted in an evaluation of responses to acid input, primarily focusing on sulphur, nitrogen, base cations, and major nutrients. The second is a specific analysis on the effects of exposure and dry deposition of emitted substances on the needle cuticle, the wax-based outer coating of the needle.

Collection of needles for the epicuticular wax analysis is to be completed before acquisition of needle samples for routine analyses.

9.3.4.1 Collection of Needles for Epicuticular Wax Analyses

Deposits of epicuticular wax comprise the outermost portion of the leaf cuticle and are important for plant health and survival, providing a layer of protection to damage caused by environmental change (Jenks and Ashworth, 1999). Epicuticular wax biosynthesis and structure are sensitive to environmental change, including physical (temperature, relative humidity, soil moisture) and chemical (inorganic and organic air pollutants) changes (Baker, 1982; Percy et al., 1994, 2009). Pollutant-induced changes to leaf surface wettability across a range of plant forms have been linked with underlying changes in chemical composition of the epicuticular was layer on the leaf surface (Percy and Baker, 1988, 1991; Percy et al., 1990, 1992).

9.3.4.1.1 Needle Sampling for Epicuticular Wax Structure Analysis

Twenty-five fascicles, comprising 50 needles, are to be removed from the middle third of each current year internode harvested from each off-plot tree, at each site. These needles are to be placed into labelled (**SAMPLE LABELLING PROCEDURE (#1)**) 20 ml borosilicate vials, taking care to not abrade any of the needles. The vials are to be capped, and placed upright into a cooler containing ice. Upon return from the field each day, the needle samples are to be transferred to a refrigerator.

9.3.4.1.2 Needle Sampling for Epicuticular Wax Composition Analysis

Fifty (25 fascicle pairs) current-year needles are to be removed from each of the branches harvested from the off-plot trees. The 50 needles are to be placed in labelled (**SAMPLE LABELLING PROCEDURE (#1)**) borosilicate vials, capped and placed in a cooler containing ice. Upon return from the field, the vials are to be frozen (-20°C). Once all samples have been obtained, the sample set is to be shipped to the laboratory (**SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**). The samples are to remain frozen to the extent possible for the duration of shipment (in a cooler with sufficient ice to last the shipment period).

9.3.4.2 Collection of Needles for Routine Analyses

In 1998, samples of needle age classes from each of 10 trees were collected combined into a single, composite sample. In 2001, needles from each of the age classes from each branch were separately sampled. In 2004, a branch from each of five trees was excised, and needles from the same age class (CAG, Age-1, Age-2) being combined from all branches to create three composite samples, one for each age class, per site.

Compositing of samples from separate trees is no longer permitted. The procedure (**FOLIAR SAMPLE (ROUTINE) COLLECTION & CHECKLIST (#30)**) requires that samples of CAG, Age-1 and Age-2 age classes from each of the five off-plot trees be acquired and separately bagged. Samples are to be stored and transported according to the **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**).

9.4 Routine Analyses of Foliar Samples

Selection of a laboratory (or laboratories) should be made in advance of the field program. The laboratory(ies) selected should be made aware of all analyses required, again in advance of the field program, such that when the samples arrive, laboratory staff are prepared to properly receive them and initiate the analyses, or place the samples in appropriate storage. Field staff must also explicitly request the required analysis (or analyses) on the chain-of-custody form(s). This is a confirmatory step; should the request on the chain-of-custody form not match that expected by the laboratory, a discussion among the laboratory, field team members, project manager and/or TEEM program manager is required to ensure that the proper analysis (analyses) are completed by the laboratory.

Care in the preparation of the foliar samples for laboratory processing is required to maintain the integrity of the samples, and to prepare proper quantities of each sample for each of the

required analyses. Sample cleaning, drying and grinding are to be conducted according to the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**. Samples are to be labelled according to the **SAMPLE LABELLING PROCEDURE (#1)**.

Each of the laboratory procedures that follow requires that a precise quantity (by weight) of ground foliar tissue be analysed. The weighing of ground foliar tissues into the reaction or extraction vessels at the initiation of a laboratory procedure is to follow the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**.

9.4.1 Total Sulphur (S_t)

The total sulphur (S_t) in foliar samples consists of inorganic sulphur (S_i) and organic sulphur (S_o). The S_o fraction in foliar samples reflects the process of assimilation of S by plant tissue and the S_i fraction reflects the accumulation of S by plant tissue (Legge et al., 1988). The S_i fraction consists of elemental sulphur and SO_4^{2-}. The absolute values and the ratio of S_i:S_o can be used as indicators of plant tissue stress or recovery to changing inputs of S_i through acid deposition.

Total sulphur is measured using dry combustion using an automated sulphur analyser, according to **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

9.4.2 Inorganic Sulphur (S_i)

The procedure for determination of sulphate content in plant material is based on Brockley (2000). This involves a weak acid digestion of a foliar sample, followed by ion chromatographic analysis (**FOLIAR TISSUE INORGANIC SULPHUR (S_i) ANALYSIS PROCEDURE (#33)**).

9.4.3 Organic Sulphur (S_o) & S_i:S_o

The concentration of organic sulphur (S_o) in each foliar (needle) sample is derived through the subtraction of inorganic sulphur (S_i) concentration from total sulphur (S_t) concentration. The ratio of inorganic to organic sulphur concentrations can then be derived (**FOLIAR TISSUE ORGANIC SULPHUR (S_o) AND S_i:S_o RATIO CALCULATIONS PROCEDURE (#34)**).

9.4.4 Total Nitrogen

The abundance and chemical forms of nitrogen are of major interest when assessing the health of forest ecosystems (Schumacher et al., 1995), particularly in an area subject to deposition of elevated levels. In natural systems, nitrogen is found in a number of forms that can, under the correct chemical and microbiological conditions, convert from one form to another.

The procedure requires the analysis of total nitrogen content by dry combustion according to the **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

9.4.5 Elemental Concentrations

Acid deposition may alter soil nutrient balances, soil pH, mineralization and immobilization, ion activity, and ion diffusion (Schumacher, et. al. 1995). Acid deposition can reduce nutrient availability, and/or increase availability of elements that are toxic, and these soil effects may be reflected in the concentrations of various elements within plant tissues.

A number of elements are emitted (or have been emitted in the past) from the oil sands operations, entrained in the air emissions from the upgraders, mine fleets and regional traffic. Other elements of importance may be naturally occurring, and emitted into the atmosphere, and may affect plant growth and/or soil chemistry.

The technique used to measure elemental concentrations in plant tissues is capable of providing analytical data for a large number of elements. While many of these are present in air emissions, they are also naturally present in crustal materials. It can be difficult to distinguish between an elevated concentration in a foliage sample due to exposure to particulate emissions containing these metals, and an elevated concentration in a sample due to exposure to naturally occurring minerals in the soils at the site or in dust blown in from a distant source.

While a full scan approach provides data at little incremental laboratory cost, the incremental investment in data entry, analysis and interpretation is larger. A two-tiered approach is to be applied, segregating the data into a set of data in which concentrations of elements of interest are included (primary elements database; Table 9.1), and a second dataset that includes the concentrations of the remainder of the elements analysed (secondary elements database). This will focus attention on the former, while continuing to collect data of potential future interest without investing the time and resources into analyses and interpretations of currently minimal relevance or interest.

Table 9.1: Elements to be Included in the Priority Elements Database

Element		Emitted in Region	Nutrient	Toxic*
Aluminum	Al	Yes	No	Yes
Calcium	Ca	Yes	Macronutrient	No
Copper	Cu	Yes	Micronutrient	No*
Iron	Fe	Yes	Micronutrient	No*
Magnesium	Mg	Maybe	Micronutrient	No*
Manganese	Mn	Yes	Micronutrient	No*
Molybdenum	Mo	Yes	Micronutrient	No*
Nickel	Ni	Yes	No	Yes
Phosphorus	P	No	Macronutrient	No
Potassium	K	Yes	Macronutrient	No
Sodium	Na	Yes	(Micronutrient?)	No
Sulphur	S	Yes	Macronutrient	No*
Zinc	Zn	Yes	Micronutrient	No*

*Indicates no toxicity to vegetation at nutrient levels, toxicity at higher levels.

The **TREE TISSUE ELEMENTAL CONCENTRATIONS ANALYSIS PROCEDURE (#35)** is based on the United States Environmental Protection Agency (1996) Method 3052, and is to be used in the elemental analysis of foliar samples.

9.5 Epicuticular Wax Structure

Epicuticular wax structure is determined using Scanning Electron Microscopy, following the **EPICUTICULAR WAX STRUCTURE ANALYSIS PROCEDURE (#36)**. It is important to keep the samples cool from the time of sampling through to delivery to the laboratory.

9.6 Epicuticular Wax Composition

Epicuticular wax composition is determined from a wax sample extracted from the needle surface, following the **EPICUTICULAR WAX COMPOSITION ANALYSIS PROCEDURE (#37)**. It is important to keep the samples cool from the time of sampling through to delivery to the laboratory.

9.7 Bark

With its rough surface, bark may be a suitable tissue for the analysis for the presence and quantity of substances (particularly particulates) emitted from industrial operations (Bohm et al., 1988; Legge et al, 1988; Lotschert and Kohn, 1978; Santamaria and Martin, 1997). Tree bark is physiologically inert, such that trapped substances are not subject to tree metabolic processes, although microorganisms on the bark may take-up and process a small amount of deposited material.

Collection and analysis of bark samples from all or a subset of monitoring sites during as a component of the 6-year monitoring cycle will be determined by the TEEM committee in advance of each cycle.

9.7.1 Bark Sample Collection

Selection of a laboratory (or laboratories) should be made in advance of the field program. The laboratory(ies) selected should be made aware of all analyses required, again in advance of the field program, such that when the samples arrive, laboratory staff are prepared to properly receive them and initiate the analyses, or place the samples in appropriate storage. Field staff must also explicitly request the required analysis (or analyses) on the chain-of-custody form(s). This is a confirmatory step; should the request on the chain-of-custody form not match that expected by the laboratory, a discussion among the laboratory, field team members, project manager and/or TEEM program manager is required to ensure that the proper analysis (analyses) are completed by the laboratory.

Although bark sampling does not impair tree health, bark is not regrown and hence, a tree can be sampled only once. For this reason, bark samples are to be obtained from unmarked trees outside of the vegetation plot and off-plot tree area(s). Consequently, a sample will not be attributable to any individual tree at the site.

On the side of the tree facing the oil sands upgraders, the surface layer of bark is to be scraped into a sealable, plastic zipper bag. Only the surface layer of bark is to be sampled, taking extreme care to not sample or damage the cambium. A sharp, sturdy instrument is required (e.g., hatchet) and the blade is to be held at a steep angle. Personnel are to wear powderless nitrile gloves while collecting bark samples.

A field duplicate sample of bark material is to be obtained from 10% of the sites being sampled in a single year, rounded up to the next whole number (1 field duplicate for up to 10 sites, 2 field duplicate samples for 11 to 20 sites; 3 for 21 to 30 sites, etc.). A field duplicate is to be prepared by acquiring twice the amount of bark tissue required for a sample, mixing the material gently, and dividing the sample into two equal portions, one as the replicate, the other as the field duplicate.

Each sample is to be placed into a plastic zipper storage bag, which itself is to be placed into a second, plastic zipper storage bag. Samples are to be labelled according to the **SAMPLE LABELLING PROCEDURE (#4)**. Storage and transport of bark samples is to follow the **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**.

9.7.2 Bark Sample Preparation

Care in the preparation of the foliar samples for laboratory processing is required to maintain the integrity of the samples, and to prepare proper quantities of each sample for each of the required analyses. Sample cleaning, drying and grinding are to be conducted according to the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**.

Each of the laboratory procedures that follow requires that a precise quantity (by weight) of ground foliar tissue be analysed. The weighing of ground foliar tissues into the reaction or extraction vessels at the initiation of a laboratory procedure is to follow the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**.

9.7.3 Total Sulphur (S_t)

Total sulphur is measured using dry combustion using an automated sulphur analyser, according to **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

9.7.4 Inorganic Sulphur (S_i)

The procedure for sulfate in bark material is based on Brockley (2000). This involves a weak acid digestion of a sample, followed by ion chromatographic analysis (**FOLIAR TISSUE INORGANIC SULPHUR (S_i) ANALYSIS PROCEDURE (#33)**).

9.7.5 Organic Sulphur (S_o) & S_i:S_o

The concentration of organic sulphur (S_o) in each bark sample is derived through the subtraction of inorganic sulphur (S_i) concentration from total sulphur (S_t) concentration. The ratio of inorganic to organic sulphur concentrations can then be derived (**FOLIAR TISSUE ORGANIC SULPHUR (S_o) AND S_i:S_o CALCULATIONS PROCEDURE (#34)**).

9.7.6 Elemental Concentrations

Bark samples may be analysed for the concentrations of various elements, which due to the inert nature of the bark tissues, represents the deposition of particulates to the bark surface. This analysis is not a routine component of the 6-year monitoring cycle. Nevertheless, should it be decided that bark samples are to be collected and analysed for some or a number of elements, the **TREE TISSUE ELEMENTAL CONCENTRATIONS ANALYSIS (#35)** is to be followed. Treatment of the data from this analysis is discussed in Section 9.4.5.

10.0 LICHEN MONITORING PROGRAM

Monitoring of lichens, in particular the elemental concentrations in lichen tissues, provides a line of evidence indicative of exposure of vegetation at a site to air emissions. Lichen monitoring is a well-established approach in the evaluation of air quality, used worldwide (Berryman et al. 2004; Blett et al. 2003; Pfeiffer and Barclay-Estrup 1992; Rhoades 1999). Lichen surveys and monitoring programs have a primary function in the identification of areas potentially affected by changes in air quality.

Arboreal lichens directly respond to changes in air quality, as they obtain most nutrients and carbon from the air, making them suitable for use in air monitoring programs. Each of *Usnea lapponica*, *Evernia mesomorpha* and *Hypogymnia physodes* has been included in at least one sampling event in the Forest Health Monitoring Program.

The lichen monitoring program has two components:

1. Sampling and analysis of tissues of the arboreal lichens *H. physodes* and *E. mesomorpha*; and
2. Description of the community of epiphytic macrolichens.

In 2004, an evaluation of lichen vigour and growth was undertaken as a third component of the program. The results of this assessment did not add substantially to the understanding of lichen growth and health. The TEEM committee has suspended the lichen vigour and growth assessment, insofar as it was conducted in 2004.

Selection of a laboratory (or laboratories) should be made well in advance of the field program. The laboratory(ies) selected should be made aware of all analyses required, again well in advance of the field program, such that when the samples arrive, laboratory staff are prepared to properly receive them and initiate the analyses or place the samples in appropriate storage. Field staff must also explicitly request the required analysis (or analyses) on the chain-of-custody form(s). This is a confirmatory step; should the request on the chain-of-custody form not match that expected by the laboratory, a discussion among the laboratory, field team members, project manager and/or TEEM program manager should occur so that the proper analysis (analyses) are completed by the laboratory.

The lichen monitoring procedures are to be completed following site establishment (the first year of monitoring at a site), and every 6-years thereafter.

10.1 Lichen Tissue Collection

Care must be taken to acquire only the minimum sample required, as excessive sampling may denude the site of the lichen, compromising the long-term program.

Lichen samples are to be collected from trees that are outside of the vegetation and soil plots, as described in the **Lichen Tissue Sample Collection Procedure (#31)**. Each lichen sample is to be placed into a plastic zipper storage bag, which itself is to be placed into a second, plastic zipper storage bag. Samples are to be labelled according to the **SAMPLE LABELLING PROCEDURE**

(#1). Lichen samples are to be placed in a cooler with sufficient ice packs to maintain a constant, cool sample temperature (**SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**).

Samples are to remain cool during shipment to the laboratory (**SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**), and at the laboratory until prepared for analysis.

10.2 Lichen Tissue Analysis

Selection of a laboratory (or laboratories) should be made in advance of the field program. The laboratory(ies) selected should be made aware of all analyses required, again in advance of the field program, such that when the samples arrive, laboratory staff are prepared to properly receive them and initiate the analyses, or place the samples in appropriate storage. Field staff must also explicitly request the required analysis (or analyses) on the chain-of-custody form(s). This is a confirmatory step; should the request on the chain-of-custody form not match that expected by the laboratory, a discussion among the laboratory, field team members, project manager and/or TEEM program manager is required to ensure that the proper analysis (analyses) are completed by the laboratory.

Berryman et al. (2004) reviewed the literature in which sulphur and nitrogen accumulation in lichen tissues can be used as a means of representing the exposure of those tissues to elevated levels of these compounds in air.

10.2.1 Lichen Sample Preparation

Care in the preparation of the lichen samples for laboratory processing is required to maintain the integrity of the samples, and to prepare proper quantities of each sample for each of the required analyses. Lichen samples are to be prepared for analysis as described in the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**.

10.2.2 Sample Weighing

Each of the laboratory analyses require that a precise quantity (by weight) of ground lichen tissue be analysed. Weighing of samples is to follow the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**.

10.2.3 Total Sulphur (S_t)

Total sulphur is measured using dry combustion using an automated sulphur analyser as described in the **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

10.2.4 Total Nitrogen

Total nitrogen is measured using dry combustion using an automated sulphur analyser as described in the **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

10.3 Epiphytic Lichen Community Composition

Changes in lichen community composition may occur in response to exposure to air contaminants, as abundance of sensitive lichen species decreases and tolerant species (or species that require higher levels of substances in air) abundances increase. Epiphytic lichens, reliant on the air for nutrient and water supply, are likely the most susceptible to changes in the quality of the air. The community composition is to be characterized according to the **EPIPHYTIC LICHEN COMMUNITY COMPOSITION ASSESSMENT PROCEDURE (#39)**, which includes completion of TEEM Form 07.

11.0 FOREST EDGE MONITORING

Trees growing at an exposed stand edge are exposed to substances in the ambient air to a higher degree than are trees growing the interior of a stand (Beier, 1991, Draaijers et al., 1988, Hasselrot and Grennfelt, 1987, Lester et al., 1986, Weathers et al., 2001). This is particularly true if the forest edge faces towards the source of substance emissions. The measurement of selected tree morphological characteristics and the sampling of plant tissues at the exposed edge of a forest stand provides an opportunity to detect forest responses to changes in air quality, possibly before such indications will be observed in the interior stand vegetation.

The TEEM Committee began investigating the use of forest edges in 2000 (AMEC Earth & Environmental Limited, 2000c), and since been establishing a series of jack pine edge monitoring locations, primarily near the jack pine monitoring sites. Meteorological, air quality and/or deposition monitoring instruments and equipment have been deployed to some of the edge monitoring sites.

11.1 Edge Monitoring Site Selection

Selection of a jack pine forest edge monitoring site is to be a deliberate process, ensuring that the selected site is similar to the other edge monitoring sites in the program. Because of the restricted availability of jack pine forest edges in the region, strict adherence to a set of site selection criteria is not required. Nevertheless, minimizing variability among sites is an important factor in being able to detect the early signs of vegetation responses to air emissions.

In order to be included in the Forest Health Monitoring Program, a jack pine edge monitoring site is to meet three criteria:

1. The edge monitoring site of relatively consistent topography and ecological consistency (Ecological Analogue Type 3; Section 4.2) across an area large enough to permit establishment of a 5 m x 20 m monitoring plot containing 15 or more jack pine trees having a DBH of 10 cm or more (indicative of trees 40 to 70 years of age);
2. The top half of each tree, and the entire crown, is to receive unobstructed airflow across an open wetland, facing the direction of the oil sands emission sources; and
3. The understory must indicate the absence of a near-surface water table, in the area where the edge trees are rooted.

Depth to the water table is indicated by the presence and abundance of Labrador tea (*Ledum groenlandicum*), a species that requires relatively high soil moisture levels. Typical suitable jack pine edge monitoring sites are located on sand deposits that abut open wetlands, where the edge of the sand deposit rises abruptly from the wetland edge. A suitable jack pine edge monitoring site is indicated when the jack pine trees to be included in the edge monitoring plot are situated above the line of transition from a Labrador tea-dominated understory to a bearberry (*Arctostaphlos uva-ursi*) understory, and in the absence of substantive cover by other shrub and tree species (e.g., willow, alder, aspen, spruce).

11.2 Edge Monitoring Site Layout & Staking

A 5 m x 20 m plot, oriented parallel to the stand edge (perpendicular to the direction of air flow from the oil sands processing facilities) is to be established. The corners of this plot are to be staked with a wood stake over which a hollow, white plastic stake is installed. This provides for visual reference points (white stakes), and for detection of the plot corners in the event that the plastic markers are broken or destroyed.

A reference stake is required at each edge monitoring site. If the edge site is within sight of the reference stake at a nearby interior monitoring site, then a single reference stake may be used to map both monitoring locations (**REFERENCE STAKE INSTALLATION & GEO-REFERENCING PROCEDURE (#4)**).

11.3 Labelling and Marking Edge Plot Trees

Each standing tree within the plot is to be numbered and labelled according to **TREE NUMBERING & LABELLING PROCEDURE (#5)**.

A tree is deemed to be within the edge monitoring plot if its point of germination occurred in the plot. Trees that germinated within the plot, but which lean outside the plot are considered to be in the plot. Conversely, trees that germinated outside the plot but which lean into the plot are to be excluded. Trees that fork at a height of 1.3 m or lower are considered to be two trees, and each stem is to be separately numbered and tagged. Trees that grow in clumps (rare for jack pine) having germinated from the same location are deemed to be plot trees if the germination point is in the plot – all stems in the clump having reached 10 cm DBH are to be separately numbered and tagged.

11.4 Edge Monitoring Site Information

Site information for a new edge monitoring site is to be acquired according to the **SITE INFORMATION PROCEDURE (#3)**, which includes completion of TEEM Form E01. Practitioners should complete this form in detail, ensuring that a person who had not visited the site is able to visualize the location of the plot on the terrain. Site information and observations should be from the perspective of the vegetation plot.

11.5 Edge Monitoring Plot Tree Map

Trees are to be mapped within edge monitoring plot, according to the **TREE MAPPING MEASUREMENTS PROCEDURE (#24)**, which includes completion of TEEM Form E02. From these measurements, a plot map is to be generated (at a later date). The tree map is to include an arrow to true North, the bearing of the Reference Line, and arrows showing the direction and bearing to the Suncor, Syncrude, CNRL and Nexen oil sands processing facilities. The procedure described in Section 6.2 is to be used to map edge plot trees, with the exception that the origin from which measurements are taken is the edge monitoring plot corner closest to the reference stake.

11.6 Edge Monitoring Site Drawing

An edge monitoring site tree map is to be prepared at a scale that permits presentation of the plot location, the reference stake, other site features (cutlines, helipad, trails), supplementary monitoring equipment (passive or meteorological monitoring towers, PRS™ probes, IER collectors) and if nearby, the interior site plots, on a single letter-sized page. The scale and a scale bar, an arrow showing true North, an arrow showing the bearing (relative to true North) to the each of the oil sands upgrading facilities (Syncrude, Suncor, CNRL, Nexen), and the GPS coordinates of the reference stake are to be included.

Figure 4.4 (Section 4.3.6) shows a site drawing that includes both an interior monitoring site and a companion edge monitoring site. Should the edge monitoring site be distant from the interior site (i.e., the interior stand reference stake is not visible from the edge site), then a separate drawing for the edge monitoring site is required. The direction provided in Section 4.3.6 applies to the derivation of the edge monitoring site drawing.

11.7 Edge Monitoring Site Protection

At the conclusion of the site establishment program, an application for a disposition under the *Public Lands Act* is to be prepared, according to the common procedure ***PUBLIC LANDS ACT* DISPOSITIONS PROCEDURE (#6)**

11.8 Edge Monitoring (Routine) Program

Because of the greater exposure of trees at stand edges to air emissions and deposition, changes in soil chemistry, forest health and/or tree growth are expected to occur before such changes occur in the soil and vegetation plots internal to the stand. Monitoring activities at the edge sites focuses on the core soil and vegetation elements of the TEEM program on a 3-year cycle, designed to provide data sufficient to detect change while preserving the integrity of the site for long-term monitoring.

11.8.1 Tree Data

Tree data are required from each numbered and mapped tree within the vegetation plot; these data are to be obtained according to the **TREE DATA PROCEDURE (#28)**, which includes completion of TEEM Form E03. During the measurement process, tree tags and DBH reference marks are to be checked and as required, repaired or replaced.

11.8.2 Tree Condition & Health Assessments

An assessment of the health and condition of each of the labelled edge monitoring trees is to be conducted, prior to the excision of branches for detailed examination of branches and sampling of needles. This data collection procedure is to follow the **TREE CONDITION & HEALTH ASSESSMENT PROCEDURE (#27)**, which includes completion of TEEM Form E04.

11.8.3 Selection of Trees for Sampling

Selection of five trees at random from the pool of edge monitoring site trees for sampling each cycle will spread the damage caused by destructive sampling among the trees, extending the longevity of the edge monitoring site trees overall.

Five trees at each site are to be randomly selected in advance of the field program. Because the number of available trees varies among sites, a separate random number process is required for each site. Random numbers applied during a sampling cycle are to be recorded on TEEM Form E06 (**TREE SHOOT DATA PROCEDURE (#29)**).

A sixth random number, excluding the five already chosen, is to be selected. This sixth number represents the tree from which a branch is to be excised, should three cut branches from one of the five primary selected trees not fall to the ground. Use of the sixth tree, if required, is to be recorded on TEEM Form E06 (**TREE SHOOT DATA PROCEDURE (#29)**).

11.8.4 Branch Excision

Needle sampling is to be conducted between August 1 and September 15. Current annual growth (CAG) will be complete or nearly so, physiological responses to the onset of autumn conditions (night frost) will be minimal, and the extent and magnitude of insect or pathogenic microorganisms will be less than expected later in the year.

A branch from each of the five selected edge monitoring site trees is to be cut from the upper third of the canopy, on the side of the tree facing the oil sands processing facilities. The branch is to be cut from the tree as close to the trunk as safely possible, using a pole pruner.

Cut branches may hang up in the canopy. Within the limits of safety associated with the pole pruner, gentle attempts to dislodge the branch may be made. If a branch cannot be dislodged, another branch is to be selected and cut. A maximum of three branches are to be cut from any one tree. In the event that all three cut branches hang up in the canopy, the tree is to be left alone, and the sixth randomly chosen tree is to be used to acquire the necessary sample.

The cut branch is to be photographed, and a record of photographs is to be entered onto TEEM Form E06 (**TREE SHOOT DATA PROCEDURE (#29)**).

This activity poses significant safety risks. Each member of this crew, and any personnel within 1.5 tree heights, is to wear a hard hat, safety glasses, leather gloves, hard-toed boots, full-length pants, and a long-sleeved shirt. All personnel at the site must be made aware of the pruning activity.

11.8.5 Internode Length & Defoliation Estimate

The length of each internode on the each of the five main branches is to be measured and defoliation estimated according to the **TREE SHOOT DATA PROCEDURE (#29)**, which includes completion of TEEM Form E06.

11.8.6 Foliar (Needle) Sample Collection

Two separate sample types are to be collected for chemical analyses. One, termed “routine”, encompasses the suite of analyses that are typically conducted in an evaluation of responses to acid input, primarily focusing on sulphur, nitrogen, base cations, and major nutrients. The second is a specific analysis on the effects of exposure and dry deposition of emitted substances on the needle cuticle, the wax-based outer coating of the needle.

Collection of needles for the epicuticular wax analysis is to be completed before acquisition of needle samples for routine analyses.

11.8.6.1 Collection of Needles for Epicuticular Wax Analyses

Deposits of epicuticular wax comprise the outermost portion of the leaf cuticle and are important for plant health and survival, providing a layer of protection to damage caused by environmental change (Jenks and Ashworth, 1999). Epicuticular wax biosynthesis and structure are sensitive to environmental change, including physical (temperature, relative humidity, soil moisture) and chemical (inorganic and organic air pollutants) changes (Baker, 1982; Percy et al., 1994, 2009). Pollutant-induced changes to leaf surface wettability across a range of plant forms have been linked with underlying changes in chemical composition of the epicuticular was layer on the leaf surface (Percy and Baker, 1988, 1991; Percy et al., 1990, 1992).

11.8.6.1.1 Needle Sampling for Epicuticular Wax Structure Analysis

Twenty-five fascicles, comprising 50 needles, are to be removed from the middle third of each current year internode harvested from each off-plot tree, at each site. These needles are to be placed into labelled (**SAMPLE LABELLING PROCEDURE (#1)**) 20 ml borosilicate vials, taking care to not abrade any of the needles. The vials are to be capped, and placed upright into a cooler containing ice. Upon return from the field each day, the needle samples are to be transferred to a refrigerator.

11.8.6.1.2 Needle Sampling for Epicuticular Wax Composition Analysis

Fifty (25 fascicle pairs) current-year needles are to be removed from each of the branches harvested from the off-plot trees. The 50 needles are to be placed in labelled (**SAMPLE LABELLING PROCEDURE (#1)**) borosilicate vials, capped and placed in a cooler containing ice. Upon return from the field, the vials are to be frozen (-20°C). Once all samples have been obtained, the sample set is to be shipped to the laboratory (**SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**). The samples are to remain frozen to the extent possible for the duration of shipment (in a cooler with sufficient ice to last the shipment period).

11.8.6.2 Collection of Needles for Routine Analyses

In 1998, samples of needle age classes from each of 10 trees were collected combined into a single, composite sample. In 2001, needles from each of the age classes from each branch were separately sampled. In 2004, a branch from each of five trees was excised, and needles

from the same age class (CAG, Age-1, Age-2) being combined from all branches to create three composite samples, one for each age class, per site.

Compositing of samples from separate trees is no longer permitted. The procedure (**FOLIAR SAMPLE (ROUTINE) COLLECTION & CHECKLIST (#30)**) requires that samples of CAG, Age-1 and Age-2 age classes from each of the five off-plot trees be acquired and separately bagged. Samples are to be stored and transported according to the **SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**.

11.8.7 Foliar Sample Analyses

Selection of a laboratory (or laboratories) should be made in advance of the field program. The laboratory(ies) selected should be made aware of all analyses required, again in advance of the field program, such that when the samples arrive, laboratory staff are prepared to properly receive them and initiate the analyses, or place the samples in appropriate storage. Field staff must also explicitly request the required analysis (or analyses) on the chain-of-custody form(s). This is a confirmatory step; should the request on the chain-of-custody form not match that expected by the laboratory, a discussion among the laboratory, field team members, project manager and/or TEEM program manager is required to ensure that the proper analysis (analyses) are completed by the laboratory.

Care in the preparation of the foliar samples for laboratory processing is required to maintain the integrity of the samples, and to prepare proper quantities of each sample for each of the required analyses. In most cases each sample will be divided into two parts, one for drying and grinding in preparation for the laboratory procedures, one for re-bagging and storage (frozen), should laboratory analyses be repeated, or new analyses requested, and ultimately for archiving. Sample preparation is to be conducted according to the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**. Samples are to be labelled according to the **SAMPLE LABELLING PROCEDURE (#1)**.

Each of the laboratory procedures that follow requires that a precise quantity (by weight) of ground foliar tissue be analysed. The weighing of ground foliar tissues into the reaction or extraction vessels at the initiation of a laboratory procedure is to follow the **TREE & LICHEN TISSUE SAMPLE PREPARATION PROCEDURE (#32)**.

11.8.7.1 Total Sulphur

The total sulphur (S_t) in foliar samples consists of inorganic sulphur (S_i) and organic sulphur (S_o). The S_o fraction in foliar samples reflects the process of assimilation of S by plant tissue and the S_i fraction reflects the accumulation of S by plant tissue (Legge et al., 1988). The S_i fraction consists of elemental sulphur and SO_4^{2-}. The absolute values and the ratio of S_i:S_o can be used as indicators of plant tissue stress or recovery to changing inputs of S_i through acid deposition.

Total sulphur is measured using dry combustion using an automated sulphur analyser, according to **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

11.8.7.2 Inorganic Sulphur (S_i)

The procedure for sulfate in plant material is based on Brockley (2000). This involves a weak acid digestion of a foliar sample, followed by ion chromatographic analysis (**FOLIAR TISSUE INORGANIC SULPHUR (S_i) ANALYSIS PROCEDURE (#33)**).

11.8.7.3 Organic Sulphur (S_o) & S_i:S_o

The concentration of organic sulphur (S_o) in each foliar (needle) sample is derived through the subtraction of inorganic sulphur (S_i) concentration from total sulphur (S_t) concentration. The ratio of inorganic to organic sulphur concentrations can then be derived (**FOLIAR TISSUE ORGANIC SULPHUR (S_o) AND S_i:S_o CALCULATIONS PROCEDURE (#34)**).

11.8.7.4 Total Nitrogen

The abundance and chemical forms of nitrogen are of major interest when assessing the health of forest ecosystems (Schumacher et al., 1995), particularly in an area subject to deposition of elevated levels. In natural systems, nitrogen is found in a number of forms that can, under the correct chemical and microbiological conditions, convert from one form to another.

The procedure requires the analysis of total nitrogen content by dry combustion according to the **TOTAL SULPHUR, NITROGEN & CARBON ANALYSIS PROCEDURE (#17)**.

12.0 ION EXCHANGE RESINS

12.1 Plant Root Simulators (PRS™ Probes)

Changes in soil chemistry in response to acid input may alter soil nutrient balances, soil pH, mineralization and immobilization, ion activity, buffer power, and ion diffusion. The availability of nutrients to plants is driven by both the presence and behaviour of the nutrient within the soil (Qian and Schoenau, 2002). Traditional laboratory techniques primarily focus on the presence of the nutrients, mainly in soluble forms. In some cases the laboratory technique can focus on the form of a nutrient that is possible for plants to use. However, nutrients are not available unless they move to roots where they can be absorbed. Nutrient movement in the soil is highly variable, being controlled by soil moisture and temperature, mineralization and immobilization, ion activity, buffer power, and ion diffusion.

The Plant Root Simulator (PRS™) probe is a tool designed to mimic a plant root in a manner that allows for an evaluation of the plant nutrients that are mobile within the soil. Following burial of PRS™ probes for a period of time, the probes are recovered and the resin is extracted; the extractant is analysed for the concentration of cations or anions, depending upon the resin used.

12.1.1 PRS™ Deployment

Four each of the cation and ion PRS™ probes are to be deployed at each edge and interior monitoring site. Probes are to be retrieved and replaced twice each year, once in the spring as soon as possible after the soil has thawed and once in the fall prior to freeze-up. Typically, the spring retrieval and replacement program occurs in mid-May, and the fall program in mid-October.

At an angle of approximately 30° angle (from vertical), each PRS™ probe is to be pushed by hand into the upper soil horizon. The resin membrane must be completely buried in the soil. A monofilament line is to be tied to the end of each probe, and all lines tied to a pigtail stake. A short length of flagging tape is to be tied to the pigtail stake to identify the area in which the probes have been deployed.

To test the manufacture process, and the quality of the batch of PRS™ probes used, four of PRS™ probes are to be wrapped together in a moist (distilled/deionized water) paper towel, and sealed in a plastic zipper bag. Four anion PRS™ probes are to be similarly wrapped and sealed. These bags are to be placed into a fridge (4°C) for the duration of the deployment period. These blank probes are to be returned to the Western Ag Innovations laboratory for analysis as a part of the larger set of PRS™ probes.

The PRS™ probes are not to be labelled, as materials used in labelling may leach substances into the soil solution and compromise the validity of the analytical result.

12.1.2 PRS™ Probe Retrieval

Retrieval of probes pushed into the soil surface horizon requires gentle hand pressure, minimizing stress on the probe, and in particular, minimizing the potential for tearing of the membrane. Retrieved PRS™ probes are to be handled according to Hangs et al. (2002):

1. Rinse each PRS™ probe individually with deionized water and gently hand scrub to remove soil from the probes. Residual material on the probes will significantly affect the analyses and results. A high pressure hand pump filled with deionized water and a plastic scrub brush may be required;
2. Shake off excess water;
3. Seal the cation PRS™ probes from one site together in a labelled (**SAMPLE LABELLING PROCEDURE (#1)**) plastic zipper bag; and
4. Seal the anion PRS™ probes from one site together in a labelled (**SAMPLE LABELLING PROCEDURE (#1)**) plastic zipper bag.

Retrieved PRS™ probes, including the blanks, are to be stored, transported from the field, and shipped to the Western Ag Innovations laboratory for analysis (**SAMPLE STORAGE & SHIPPING PROCEDURE (#2)**. Chain-of-custody forms are to be completed and transmitted to the laboratory along with the PRS™ probes.

12.1.3 Laboratory Analysis of PRS™ Probes

As a commercial item, the analysis of recovered PRS™ probes is to be completed by the laboratory of Western Ag Solutions. Hangs et al. (2002) describe the analytical procedure.

12.2 Ion Exchange Resins (IER) for Deposition Monitoring

At a number of sites, throughfall (at interior jack pine monitoring sites) and bulk (open areas generally near edge monitoring sites) precipitation samples were collected with passive collectors based on a mixed bed (cation and anion resin) ion exchange resin columns (Fenn and Poth, 2004; Fenn et al., 2009). These resins retain the ions in precipitation collected by a polyethylene funnel. The major advantage of the IER method is that sample collection continues in the field without the need for repeated field trips to collect liquid samples or the need for repeated sample analyses from each collector.

IER columns are to be prepared by pouring 25 g of the mixed bed ion exchange resin beads into PVC tubes (20 cm in length and 1.25 cm I.D.) as aqueous slurry and then further rinsed with distilled water.

12.2.1 IER Deployment & Retrieval

IER columns are to be deployed and retrieved twice each year. Typically, the spring retrieval and replacement program occurs in mid-May, and the fall program in mid-October. At each retrieval the columns are to be capped, and labels examined and refreshed or replaced as necessary.

One column, the blank, is to remain capped while deployed into the field. This column is to be analysed along with the columns that were exposed to collected precipitation.

12.2.2 Laboratory Analysis of IER

IER columns are to be extracted with 75 ml of 1N KI, followed by a second extraction with 75 ml of 1N KI.

Nitrate and sulfate concentrations in the column extracts are to be analyzed by ion chromatography (Dionex DX-1600, Sunnyvale, CA) using a procedure modified from Simkin et al. (2004). Ammonium concentrations in the KI extracts were determined colorimetrically (Technicon TRAACS autoanalyser).

Columns designated for base cation analysis received an additional extraction of 200 ml KCl. The KI and KCl extracts were proportionately combined and analyzed for Ca^{2+}, Mg^{2+} and Na^{+} by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Atmospheric deposition fluxes were determined by extrapolating from the area of the collector opening and the amounts of inorganic N and S or base cations that were extracted from the IER columns (Fenn and Poth, 2004; Fenn et al., 2009).

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