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Proposed Exclusion Depths for the Ecological Direct Contact Exposure Pathway at Remote Alberta Green Zone Sites

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Table of Contents

Page

List of Tables

Page

List of Appendices

Executive Summary

The Alberta Tier 1 guidelines document allows the exclusion of the ecological direct contact exposure pathway from the Tier 1 guideline value for petroleum hydrocarbon fractions F1 to F4 at depths greater than 3 m. Following discussions with key regulatory personnel in Alberta Environment and Sustainable Resource Development (ESRD), it was determined that there may be scope for this exclusion depth to reflect more closely the maximum rooting depth for trees and shrubs at forested sites that are remote from human habitation. This project was initiated to develop defensible maximum rooting depths for typical Alberta coniferous and deciduous tree species and associated shrub understory. The findings of this document are applicable to sites in the Green Zone of Alberta.

The approach taken to determining maximum rooting depths was firstly to compile and summarize all relevant rooting depth data from the literature, and then to conduct an extensive field verification program across the Green Zone of Alberta. This document reports the results of both these tasks.

Literature Review

Relevant species were identified by considering characteristic tree and shrub species native to forested natural regions of Alberta. Available information on rooting depth was compiled for relevant species. Available information on the distribution with depth of soil invertebrates and soil microbes was also compiled. The data were used to develop conservative values for the maximum rooting depth for coarse and fine soils, for all species in forested areas of the Green Zone.

Field Verification Study

A total of 16 sites with fine-grained soils across the Green Zone of Alberta were identified for verification of the maximum rooting depth values developed in the literature review. Trenches were excavated at each of these sites adjacent to mature trees and the maximum rooting depth recorded for each.

Summary and Application

Maximum effective rooting depth values developed in this project for trees and other plant species in the Green Zone of Alberta, based on literature and new field data are:

- 1.5 m for fine-grained soils; and,
- 3.0 m for coarse-grained soils.

Available data presented for soil invertebrates and soil microbes indicate that the vast majority of these biota are present in soils at depths less than 1.5 m.

The ecological direct contact exposure pathway in the Alberta Tier 1 guidelines can be excluded at 3.0 m for F1-F4 hydrocarbon fractions at any site. The data provided herein provide a scientific rationale for excluding the ecological direct contact pathway at 1.5 m at sites that meet all of the following conditions:

1. The site is located in a forested area of the Green Zone of Alberta.
2. The site is fine-grained.
3. The site is on public land administered by Alberta Environment and Strategic Resource Development (ESRD).
4. The site is located remote from human habitation and future disturbance of the subsoil is not anticipated.

1.0 INTRODUCTION

The Alberta Tier 1 guidelines document (AENV 2010, Section 2.3.4) allows the exclusion of the ecological direct contact exposure pathway from the Tier 1 guideline value for petroleum hydrocarbon fractions F1 to F4 at depths greater than 3 m. These are currently the only chemicals/groups for which this exclusion is permitted, as AENV (2010) only allows this exclusion where a management limit is available and these are the only chemicals for which AENV (2010) provides management limits.

Following discussions with key regulatory personnel in Alberta Environment and Sustainable Resource Development (ESRD), it was determined that there may be scope for this exclusion depth to reflect more closely the maximum rooting depth for trees and shrubs at forested sites that are remote from human habitation.

Defensible data for maximum rooting depths applicable to forested sites in Alberta were not available prior to the current project. Accordingly, this project was initiated to develop defensible maximum rooting depths for typical Alberta coniferous and deciduous tree species and associated shrub understory. The findings of this document are therefore applicable to sites in the forested areas of Alberta, which generally correspond to the Boreal Forest Natural Region, Foothills Natural Region, and parts of the Rocky Mountain Natural Region of Alberta (Alberta 2006) (Figure 1). These areas correspond approximately to the Green Zone of Alberta (Figure 2).

The approach taken to determining maximum rooting depths was firstly to compile and summarize all relevant rooting depth data from the literature, and then to conduct an extensive field verification program across the Green Zone of Alberta. This document reports the results of both these tasks.

1.1 Objective, Purpose, and Scope of Work

The overall objective of this project was to determine the maximum effective rooting depth for boreal tree and shrub species in the Green Zone of Alberta. The purpose of the project is to support the exclusion of the ecological direct contact exposure pathway based on rooting depth at sites in the Green Zone of Alberta that are remote from human habitation.

The scope of work for this project was as follows.

- Review the relationship between the application of the soil eco-contact pathway and plant rooting depths in the Alberta Tier 1 framework.
- Literature study:
  - Identify relevant tree and shrub species applicable to forested areas of Alberta.

- Note that agricultural areas and areas of native grassland are out of the scope of this report.
- Research available information in the published literature on root depth profiles, and in particular, maximum rooting depth, for relevant species.
- Consider coarse and fine soils separately, if appropriate.
- Research available information on the depth profile for soil invertebrate populations.
- Research available information on the depth profile for soil microbe populations.
- Compare rooting depth profiles with available depth profile information on soil invertebrates and microbes to determine which of these concerns is likely to be limiting.

- Field verification:
  - Identify appropriate sites representative of the range of conditions across the Green Zone of Alberta.
  - Develop a field protocol for determining maximum rooting depth at each site.
  - Based on the field protocol, conduct intrusive investigations at each site to determine the maximum rooting depth at each.
- Based on the literature study and the field verification, develop depths below which it would be appropriate to exclude the ecological direct contact exposure pathway in the Alberta Tier 1 and Tier 2 guidelines framework.
- Generate a report summarizing the above.

1.2 Acknowledgements

This work was made possible by funding from the following organizations:

- Petroleum Technology Alliance Canada (PTAC) (2011 funding; PTAC project #09-9178-50).
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2.0 BACKGROUND

Alberta Environment (AENV 2010) publishes Tier 1 soil remediation guidelines for a range of chemical contaminants which consider a number of exposure pathways including direct contact of ecological receptors with soil. Ecological receptors considered within this pathway include terrestrial plants, soil invertebrates and soil microbes (terrestrial wildlife are considered separately via the soil and food ingestion pathway). The protection of plants and soil invertebrates is achieved through the ecological direct soil contact guideline. The protection of soil microbial function is achieved through the nutrient and energy cycling check. All three of these receptor groups are considered in this document.

For adverse effects to occur on terrestrial plants, soil invertebrates, or soil microbes, there must be direct contact between the organism and the contaminant in soil. For subsoils below the rooting zone of relevant plant species and below the depth at which the vast majority of soil invertebrates and microbes are present, there is essentially no contact between contaminant and receptor and the ecological direct contact exposure pathway can safely be excluded. This is acknowledged in Section 2.3.4 of AENV (2010), which permits the exclusion of the ecological direct contact exposure pathway below 3 m for hydrocarbon fractions F1 to F4. It is understood through discussion with key ESRD personnel that the rationale for the 3 m exclusion depth was based not only on plant rooting depths, but also on the depth at which soil disturbance might reasonably be anticipated for construction projects in urban or agricultural settings.

At remote Green Zone sites, human disturbance of the subsoil profile is not expected; therefore, it is appropriate to base the exclusion depth more closely on maximum expected plant rooting depths and the depth where the vast majority of the soil invertebrates and soil microbes are present. Accordingly, this report is focused on compiling available data and, where appropriate, collecting new data to define these depths.

3.0 LITERATURE REVIEW

3.1 Relevant Species

This section provides a summary of some of the species commonly found in forested areas of Alberta. It was not feasible within the scope of the present study to research the rooting profiles of all possible forest plant species that could be present in Alberta. The approach taken was to identify characteristic native species in the Boreal Forest, Foothills, and Rocky Mountain Natural Regions of Alberta, as defined in Alberta (2006). Characteristic trees of these regions (depending on soil type and situation; Alberta 2006) include:

- aspen (*Populus tremuloides*);
- balsam poplar (*Populus balsamifera*);
- white birch (*Betula papyrifera*);
- white spruce (*Picea glauca*);
- black spruce (*Picea mariana*);
- tamarack (*Larix laricina*);
- lodgepole pine (*Pinus contorta*); and
- jack pine (*Pinus banksiana*).

Some characteristic shrubs of these regions (depending on soil type and situation; Alberta 2006) include:

- beaked hazel (*Corylus cornuta*);
- bearberry (*Arctostaphylos uva-ursi*);
- common juniper (*Juniperus occidentalis*);
- labrador tea (*Ledum groenlandicum*);
- green alder (*Alnus viridis*);
- prickly rose (*Rosa acicularis*);
- bog cranberry (*Vaccinium vitis-idaea*); and
- bog birch (*Betula glandulosa*).

In addition, a wide range of grass, sedge, and forb species may be present.

3.2 Rooting Depth Data

3.2.1 Background

Various forms of data are available relating to tree and shrub rooting depths. Canadell *et al*. (1996) compiled data on the maximum rooting depth found for a range of species on a worldwide basis and found that, in arid conditions, a few roots of some species can extend down to surprising depths (in a few cases, over 20 m, and up to a maximum of 63 m for *Boscia albitrunca* in the central Kalahari desert, Botswana). Recorded maximum depths for most tree and shrub species are much less, typically 1 to 3 m depending on species. However, even these data are of only partial relevance to the current study because they give no information on the depth range in which a plant has most of its roots and from which it takes the majority of its water and nutrients.

Effective root depth or zone may be a more useful concept in some circumstances. Effective root depth is defined by FAO (1978) as the depth from which a plant takes 80% of its total water intake.

Tree rooting depth studies do not typically attempt to generate a numerical relationship between root mass and depth. However, the more detailed studies often provide careful sketches of the root systems of excavated trees, and these proved useful in estimating the depth above which certain fractions of the roots occur.

3.2.2 Approach

This study compiles research that provides information on the distribution of roots with depth.

The overall approach taken in this study was as follows.

5. Available data on rooting depth were compiled and tabulated, together with an indication of the type of data (*e.g*., maximum rooting depth, effective rooting depth, depth accounting for a certain proportion of the root mass, *etc*.).
6. The deepest rooted species likely to be widely distributed within the area were identified.
7. Available information for those species was used to develop a conservative value for maximum effective rooting depth.

3.2.3 Rooting Depth Data – Trees

The root structure of tree species is distinct from that of typical crop and grass species in that a significant proportion of the root biomass may be in a relatively shallow lateral root system, and deeper tap roots may or may not form, depending on species and conditions.

Qualitative and quantitative data providing information on the rooting depth of the tree species identified in Section 3.1 were compiled. Rooting depth information was conveyed in the source

documents in a variety of ways, including maximum root depth, effective rooting depth, depth of the "majority of roots" (assumed to be essentially equivalent to effective rooting depth), the depth accounting for a certain percentage of roots, and others. A preliminary examination of rooting depth data for Alberta tree species allowed shallower and deeper rooted species to be identified.

Available rooting depth information for shallower rooted Alberta tree species is summarized in Table 1.

Table 1 Rooting Depth for Alberta Trees – Shallower Rooted Species

Common Name	"Rooting Depth" (cm)	Type of Data	Source
Aspen	11	average depth of laterals	Mundell *et al*. (2007)
Aspen	60-90	max depth of fine feeding roots	Burns and Honkala (1990b)
Aspen	100	majority of roots	Strong and La Roi (1983)
Balsam poplar	13-42	effective rooting depth	Brockheim *et al*. (2003)
Black spruce	20	majority of roots	Burns and Honkala (1990a)
Black spruce	30	98% of roots	Bannan (1940)
Black spruce	30	max root depth	Strong and La Roi (1983)
Tamarack	30	majority of roots (9 of 10 trees)	Bannan (1940)
Tamarack	30	max root depth	Strong and La Roi (1983)
Tamarack	30	majority of roots	Burns and Honkala (1990a)
Tamarack	120	max root depth (1 extreme case)	Bannan (1940)
White birch	50	max root depth	Titus *et al*. (1998)
White birch	60	majority of roots	Burns and Honkala (1990b)
White spruce	30	87% of roots	Bannan (1940)
White spruce	30	85% of roots	Burns and Honkala (1990a)
White spruce	50	max root depth	Strong and La Roi (1983)
White spruce	90-120	max root depth	Burns and Honkala (1990a)

Note: Terminology for rooting depth is based on the qualitative or quantitative description provided in the source.

As can be seen in Table 1, the shallower rooted species have maximum root depths of 120 cm or less. Typically, species adapted to wet, boggy habitats (*e.g.*, black spruce and tamarack) have some of the shallowest rooting systems.

The deeper rooted Alberta tree species included lodgepole pine and jack pine. Several authors, including Horton (1958) have noted that the same species will typically be more deeply rooted in coarse, well drained soils than in fine. Horton (1958) suggests that this is due to the trees being able to meet their water and nutrient needs in fine soil without extending as deep as in coarse soil. Rooting depth data for these two deeper rooted species are presented in Table 2, and discussed below. Data are presented separately for coarse and fine soils. Studies where soil texture information was not provided or where there were multiple soil types are presented in their own group.

Table 2 Rooting Depth for Alberta Trees – Deeper Rooted Species

Common Name	Rooting Depth[a] (cm)	Type of Data[b]	Source
Coarse Soils			
Lodgepole pine	270	estimated 80% of roots	Horton (1958)
Lodgepole pine	350	max root depth	Horton (1958)
Lodgepole pine	200	max depth of water extraction	Johnston (1975)
Jack pine	160	majority of roots	Strong and La Roi (1983)
Jack pine	200	max root depth	Strong and La Roi (1983)
Jack pine	>270	max root depth	Adams and Chapman (1941)
Jack pine	>270	max root depth	Burns and Honkala (1990a)
Jack pine	30	72% of root system (n=10)	Bannan (1940)
Jack pine	>120	max root depth	Bannan (1940)
Fine Soils			
Lodgepole pine	120	estimated 80% of roots	Horton (1958)
Lodgepole pine	150	max root depth	Horton (1958)
Lodgepole pine	60	majority of roots	Bishop (1962)
Lodgepole pine	120	max root depth	Bishop (1962)
Lodgepole pine	100	max depth of water extraction	Johnston (1975)
Unspecified or Multiple Soil Types			
Lodgepole pine	<80	rooting depth for 65% of trees examined (n=167)	Nicholl (2006)
Lodgepole pine	90-120	max root depth	Simmons *et al.* (2000)
Jack pine	45	majority of roots	Burns and Honkala (1990a)

[a] Where a study considered multiple trees, the data presented here are for the deepest rooted individual tree.

[b] Terminology for rooting depth is based on the qualitative or quantitative description provided in the source.

Two of the more extensive and thorough studies available for deep-rooted Alberta tree species are the Horton (1958) study on the rooting habits of lodgepole pine, and the Strong and Le Roi (1983) study on jack pine and other species. Both these studies were conducted on Alberta field sites. Both Horton (1958) and Strong and Le Roi (1983) provided sketches of the root profiles of excavated trees, which allowed an estimate of the depth of 50% of the root mass, 80% of the root mass, and also the maximum rooting depth. Detailed data provided in or interpreted from these studies are presented in Table 3.

Table 3 Detailed Rooting Depth Information for Lodgepole and Jack Pine

Tree Number	Age	Height	Estimated Depth for 50% of Root Mass	Estimated Depth for 80% of Root Mass	Maximum Root Depth
	(years)	(m)	(m)	(m)	(m)
Coarse-Grained Soil					
Horton (1958) Data for Lodgepole Pine					
11	36	1.5	0.3	0.5	0.7
3	12	1.2	0.5	0.8	1.1
9	85	19.2	0.7	0.9	1.1
2	8	0.5	0.6	1.0	1.2
4	20	2.1	0.7	1.2	1.7
7	52	12.8	0.6	1.2	1.8
5	29	6.1	1.2	1.8	2.7
6	33	7.3	1.5	2.7	3.4
10	80	16.2	1.3	2.1	3.5
Strong and Le Roi (1983) Data for Jack Pine					
-	3	0.2	n/a	n/a	0.3
-	23	7.2	n/a	n/a	1.1
-	9	3.7	n/a	n/a	1.2
-	37	13.5	n/a	n/a	1.5
-	57	18.0	n/a	1.6	2.0

Table 3 Detailed Rooting Depth Information for Lodgepole and Jack Pine					
Tree Number	**Age**	**Height**	**Estimated Depth for 50% of Root Mass**	**Estimated Depth for 80% of Root Mass**	**Maximum Root Depth**
	(years)	**(m)**	**(m)**	**(m)**	**(m)**
Fine-Grained Soil					
Horton (1958) Data for Lodgepole Pine					
12	6	0.5	0.2	0.3	0.4
20	85	21.0	0.4	0.6	0.7
14	18	4.0	0.4	0.7	0.8
15	31	6.1	0.4	0.7	0.9
13	14	2.4	0.5	0.8	0.9
17	53	10.4	0.5	0.8	1.0
16	34	8.5	0.6	0.7	1.1
18	55	13.1	0.7	1.1	1.2
19	56	18.3	**1.0**	**1.2**	**1.5**

Data sorted by maximum root depth.
Deepest rooted tree in each category for each soil type in **red**.
n/a = not available.

3.2.4 Rooting Depth Data – Shrubs

Little information is available concerning the rooting depth of shrubby species relevant to the forested areas of Alberta (Table 4). These information are of limited use in the current study since soil texture information were not available in these studies.

Table 4 Rooting Depth for Alberta Shrub Species			
Common Name	**"Rooting Depth" (cm)**	**Type of Data**	**Source**
beaked hazel	8	average root depth	Mundell *et al.* (2007)
common juniper	15-26	max root depth	Karim and Malik (2008)
western juniper	112	max root depth	Kramer *et al.* (1996)
bearberry	91-183	max root depth	USFS (2009)

Notes: No information on soil type available for these studies.

3.3 Soil Invertebrates

The ecological soil contact guideline is also protective of soil invertebrates. Startsev and Battigelli (2008, 2010) investigated the vertical distribution of soil invertebrates in undisturbed soils from three sites in central Alberta. These authors found that the majority of soil invertebrates (>85% of the invertebrates found) were in the top 50 cm, while >95% were in the top 1.5 m of the soil profile.

Comparing the above-noted depth profile to the root profiles developed in Section 4, it appears clear that any guideline adjustments that are protective of deep rooted tree species will also be protective of soil invertebrate populations.

3.4 Soil Microbes

The nutrient and energy cycling check is protective of soil microbe function. Fierer *et al*. (2003) investigated the vertical distribution of soil microbes in two loam-textured soil profiles in California, one from a valley floor location, and one from a terrace setting some way up the valley side. These authors used three different techniques to measure microbial biomass density: phospholipid fatty acid (PLFA) analysis, chloroform ($CHCl_3$) extraction, and microbial respiration. The first two techniques measure biomass, while the last is an indication of microbe function – the ability of a microbial population to use available carbon. All three techniques indicated that microbial densities dropped rapidly with increasing depth, and the densities appeared to be related to the decreasing availability of carbon sources with increasing depth.

At 50 cm depth, the respiration measurements indicated that microbe function was only 1.4% of surface values, while the PLFA and $CHCl_3$ analyses indicated microbial biomass densities between approximately 6 and 15% of surface values.

At 100 cm depth, the respiration measurements indicated that microbe function only 0.5% of surface values, while the PLFA and $CHCl_3$ indicated microbial biomass densities between approximately 2 and 3% of surface values.

Comparing the above-noted depth profile to the root profiles developed in Section 4, it appears clear that any guideline adjustments that are protective of deep rooted tree species will also be protective of soil microbial function.

3.5 Summary and Analysis

Lodgepole and jack pine were identified as the two deepest rooting species expected to be widely distributed in forested areas of Alberta. The rooting habits of these species can vary considerably depending on soil type. In wetter areas, lodgepole pine is a shallow rooted species (Burns and Honkala 1990a). Under normal conditions the majority of the roots of lodgepole pine are found in the

top 60 cm (Simmons 2000). However, in dry, sandy soil, the deepest roots can, in extreme cases, reach as deep as 3.5 m (Table 3).

Overall, it appears clear that the rooting habits of these two deeper rooted species are significantly different in coarse and fine-grained soil, and accordingly data for these two soil textures are analyzed separately.

3.5.1 Coarse-Grained Soils

Perhaps the most extensive study of lodgepole pine rooting habits was undertaken by Horton (1958), who excavated and described the root systems of nine lodgepole pines of varying age on coarse-grained and nine on fine grained soil in Alberta (Table 3). The nine trees from coarse-grained sites had a maximum root depth up to 3.5 m (Tree #10), though the maximum effective rooting depth (depth accounting for 80% of the root mass estimated from sketches in the paper) was 2.7 m (Tree #6), and the maximum depth for an estimated 50% of root mass was 1.5 m (Tree #6).

Strong and Le Roi (1983) excavated and described the root systems of eight jack pine trees from a site close to Lesser Slave Lake in the boreal forest natural region of Alberta. The soil for all eight was an aeolian sand (coarse grained). They provided maximum root depth data for five of the trees (see Table 6) and a sketch of the root system of one of the deepest rooted of the trees, which was interpreted to give a maximum effective rooting depth for jack pine under these conditions of 1.6 m.

Bannan (1940) excavated ten adult jack pine trees growing on sandy soil close to the northeast shore of Lake Superior in Ontario. He confirmed that in these conditions, jack pine was the deepest rooted of the species investigated (the other species were larch, black spruce, white spruce, and balsam fir). His excavations went only to 4 ft (1.2 m), and found that tap roots were "still fairly large at a depth of 4 ft." He also reported that of the ten trees investigated, an average of 28% of the root system extended below 1 foot.

Adams and Chapman (1941) investigated 28 year old jack pine trees growing on sandy soil (78% to 99% sand) in plots of varying densities. They found that the deepest roots extended to more than 2.7 m. However, on the basis of the mean number of roots per square foot of soil, greater than 99% of the roots were in the top 0.6 m of soil.

Johnston (1975) compared neutron probe moisture measurements in adjacent clear-cut and untouched lodgepole pine stands in northeastern Utah on a sandy loam site, with an average tree height of 9 m. This author determined that the moisture depletion caused by the roots of the intact block of trees extended down to 2 m depth in this soil.

For coarse soils, therefore, based on the deepest rooted examples found in the literature, it appears that 1.5 m is a conservative estimate of the maximum depth of 50% of plant roots. The conservative maximum depth for 80% of plant roots is 2.7 m. The greatest rooting depth recorded in any of these studies was 3.5 m.

3.5.2 Fine-Grained Soils

With fine soil, as with coarse, the study with the most relevant data is Horton (1958), who excavated and described the root systems of nine lodgepole pines on fine grained soil in Alberta (Table 3). The nine trees from fine-grained sites had a maximum root depth of 1.5 m (Tree #19), and the maximum effective rooting depth (depth accounting for 80% of the root mass estimated from sketches in the paper) was 1.2 m (Tree #19).

Bishop (1962) also studied the rooting depth of lodgepole pine in a fine-grained soil (silt overlying clay); however, the site was underlain by basalt bedrock at a depth of approximately 1 m and, therefore, the vertical distribution of roots was truncated.

Johnston (1975) compared neutron probe moisture measurements in adjacent clearcut and untouched lodgepole pine stands in northeastern Utah on a silty clay loam site, with an average tree height of 12 m. This author determined that the moisture depletion caused by the roots of the intact block of trees extended down to 1 m depth in this soil.

In a study assessing wind throw, Nichol *et al*. (2006) mechanically overturned 167 lodgepole pine trees from 34 sites on a range of different soil types throughout the United Kingdom, and found that in 65% of cases, the root ball was 80 cm deep or less.

For fine soils, based on the deepest rooted examples found in the literature, it can be stated that at least 80% of the root mass is in the top 1.2 m of the soil, and the maximum rooting depth is 1.5 m.

4.0 FIELD VERIFICATION OF MAXIMUM ROOTING DEPTHS

Following discussion with key ESRD regulators, it was decided that the rooting depth information for coarse soil was broadly consistent with the existent exclusion depth of 3.0 m, and that this depth was confirmed as being the appropriate depth at which to exclude the ecological direct contact exposure pathway at coarse soil sites.

For fine soils, the literature survey indicated a maximum rooting depth of 1.5 m for the deepest rooted species. While much of the key literature data were in fact from Alberta, it was felt that it would be worthwhile to conduct a field study to determine whether this value could be substantiated at actual field sites at a range of fine-grained sites across the Green Zone of Alberta.

4.1 Experimental Design

The experimental design of the field verification study can be summarized as follows.

A total of 16 field sites (Figure 1) were selected from sites made available by various oilfield lease holders. Criteria for selecting sites were as follows:

- The site is located within forested regions of the boreal forest, foothills or Rocky Mountain natural regions of Alberta, and is within the Green Zone.
- The groundwater table is at least 2 m below the ground surface (to avoid situations where root development might be limited by the presence of groundwater.
- The predominant soil texture at the site is fine-grained.
- The sites selected are as widely distributed as possible.
- The site should be adjacent to undisturbed forest, such that trenches could be excavated adjacent to mature trees.

At each site, trenches were excavated adjacent to 3-5 mature trees, and observations on the rooting depth distribution were collected. The detailed field protocol developed to standardize this work is provided in Appendix B, and summarized below.

1. A note is made of the eco-site classification of the study site.
2. Three to five large trees are identified near the edge of the lease in natural vegetation. The largest and visually healthiest trees are selected as they will likely have the deepest maximum rooting depths.
3. Qualitative and quantitative measurements of the trees are collected, including type, relative health, breast diameter, estimated overall height, presence of surface roots, *etc*.
4. One or more trenches, at least 1.5 m deep, are excavated as close as possible to the stand of trees in order to maximize root exposure from all tree(s) of interest. The face(s) of the trench are cleaned.
5. A basic description of the soil profile is recorded.
6. A soil sample is collected for lab analysis of particle size from the trench face approx. 1 m below surface to verify texture (75 micron sieve).
7. Using a counting grid system, the depths for 50% of total roots, 80% of total roots, and maximum rooting depth are recorded.
8. Any roots of non-tree species (forbs, grasses, shrubs, *etc*.) are recorded by number and size as well as the root orientation and distribution. Photographs are taken to illustrate root distribution.

9. The location of the trench is fixed using GPS.

4.2 Results

The field data summary sheet for each of the 16 sites investigated is included in Appendix C.

Overall, the distribution of field sites was selected as far as possible to provide representative coverage of the Green Zone of Alberta (Figure 1), and, as such, the results of the field verification study may be considered to be representative of the Green Zone of Alberta as a whole.

The field verification study considered all roots that were visible in the excavations and therefore included shrubs, forbs and grasses as well as trees.

The maximum rooting depth for each tree investigated at each of the 16 field sites is summarized in Table 5. Consistent with the findings of the literature review, lodgepole pine and jack pine were among the deepest rooted species in the field study, though relatively deep-rooted specimens of aspen and black spruce were also recorded. The maximum rooting depth measured over 16 fine-grained sites located throughout the Green Zone of Alberta for a total of 40 trees of 9 species was 1.4 m. This is in very good agreement with the maximum rooting depth in fine soils from literature data of 1.5 m (Section 3.5.2). Overall, therefore, the maximum rooting depth of 1.5 m is confirmed for fine soils in the Green Zone of Alberta.

Table 5 Maximum Rooting Depth from Field Verification Study (Fine Soils)

Tree Species	White Spruce	Black Spruce	Jack Pine	Lodgepole Pine	Balsam poplar	Aspen	Paper birch	Green Alder	Willow
Site #	Maximum Rooting Depth (m)								
1							0.65	0.58	0.5
2	0.55	0.38	1.3			0.25			
3								0.64	0.55
4	0.4					0.6			0.65
5						1			
6	0.75					0.75			
7	0.65						0.75		
8				0.7					
8				0.82					

Table 5	Maximum Rooting Depth from Field Verification Study (Fine Soils)								
Tree Species	**White Spruce**	**Black Spruce**	**Jack Pine**	**Lodgepole Pine**	**Balsam poplar**	**Aspen**	**Paper birch**	**Green Alder**	**Willow**
Site #	**Maximum Rooting Depth (m)**								
9				1					
10				1.15					
10				1.2					
10				1.4					
11		1.2		1.2					
11				1.1					
12		0.6							
12		0.6							
12		0.6							
13				0.3		0.3			
13				0.3		0.3			
13						0.3			
14					0.9				
14					0.9				
15		0.94				1.24			
15						1.05			
16						1.38			
Maximum	**0.75**	**1.2**	**1.3**	**1.4**	**0.9**	**1.38**	**0.75**	**0.64**	**0.65**

Note: Maximum rooting depths in m.

5.0 SUMMARY AND APPLICATION

Maximum rooting depth values developed in this project for trees and other plant species in the Green Zone of Alberta, based on literature and new field data, are:

- 1.5 m for fine-grained soils; and
- 3.0 m for coarse-grained soils.

Available data presented for soil invertebrates and soil microbes indicate that the vast majority of these biota are present in soils at depths less than 1.5 m.

The ecological direct contact exposure pathway in the Alberta Tier 1 guidelines can be excluded at 3.0 m for F1-F4 hydrocarbon fractions at any site. The data provided herein provide a scientific rationale for excluding the ecological direct contact pathway at 1.5 m at sites that meet all of the following conditions:

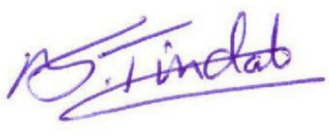
1. The site is located in a forested area of the Green Zone of Alberta.
2. The site is fine-grained.
3. The site is on public land administered by Alberta Environment and Strategic Resource Development (ESRD).
4. The site is located remote from human habitation and future disturbance of the subsoil is not anticipated.

6.0 CLOSURE

We trust that the information presented herein meets your requirements. Should you have any questions, please call the undersigned at (403) 592-6180.

Yours truly,

Millennium EMS Solutions Ltd.



Miles Tindal, M.Sc.
Principal, Risk Assessment Specialist

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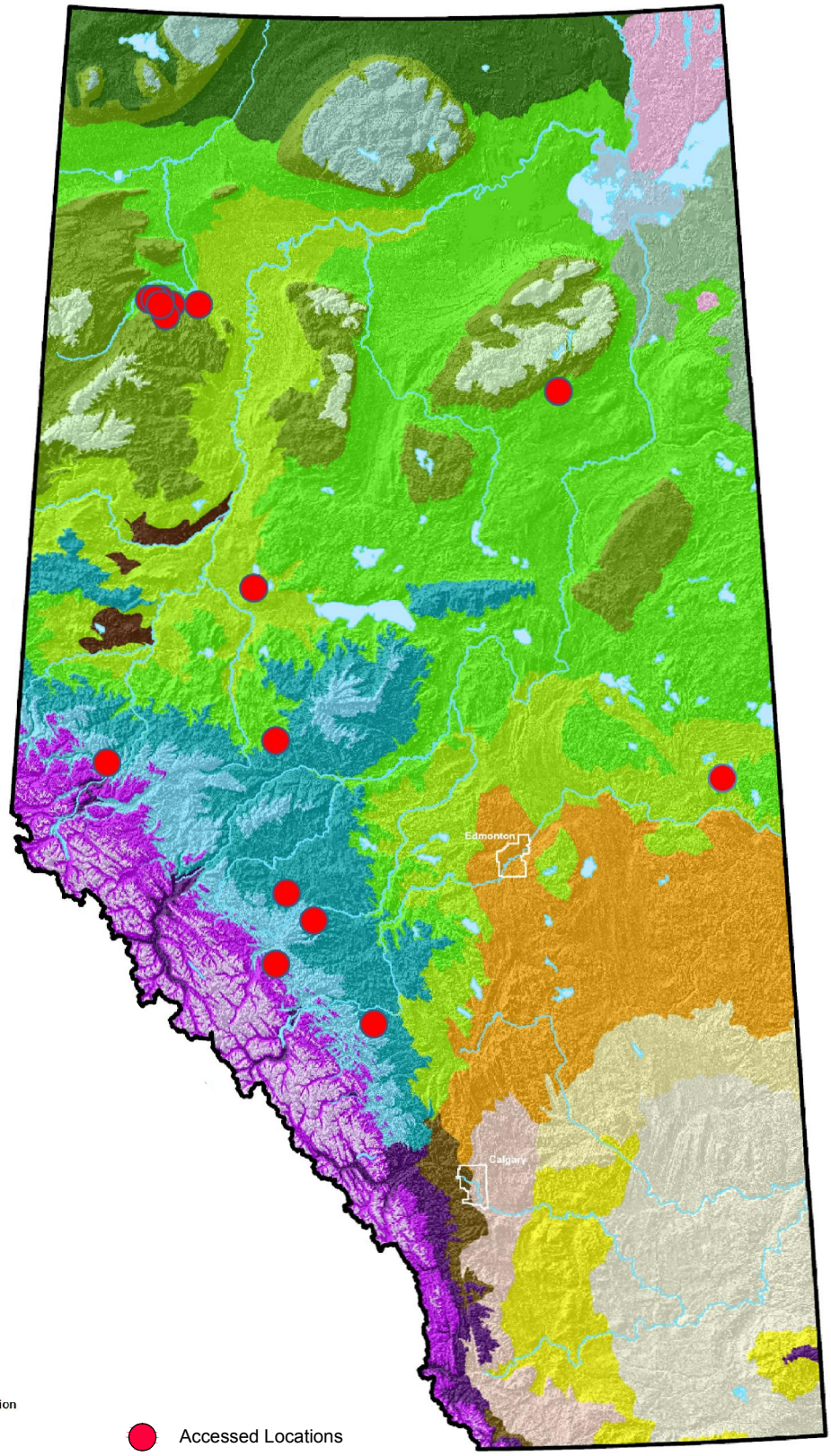
APPENDIX A: FIGURES



Alberta
GOVERNMENT OF ALBERTA

2005 Natural Regions and Subregions of Alberta

Boreal Forest Natural Region
- Central Mixedwood
- Dry Mixedwood
- Northern Mixedwood
- Boreal Subarctic
- Peace-Athabasca Delta
- Lower Boreal Highlands
- Upper Boreal Highlands
- Athabasca Plain

Rocky Mountain Natural Region
- Alpine
- Subalpine
- Montane

Foothills Natural Region
- Upper Foothills
- Lower Foothills

Canadian Shield Natural Region
- Kazan Uplands

Parkland Natural Region
- Foothills Parkland
- Peace River Parkland
- Central Parkland

Grassland Natural Region
- Dry Mixedgrass
- Foothills Fescue
- Northern Fescue
- Mixedgrass

2005 Natural Regions and Subregions of Alberta -
Alberta Sustainable Resource Development, Alberta Environment,
Alberta Community Development and Agriculture and Agri-Food Canada, June 2005

Accessed Locations

PROJECT:

Petroleum Technology Alliance Canada

MILLENNIUM
EMS Solutions Ltd.

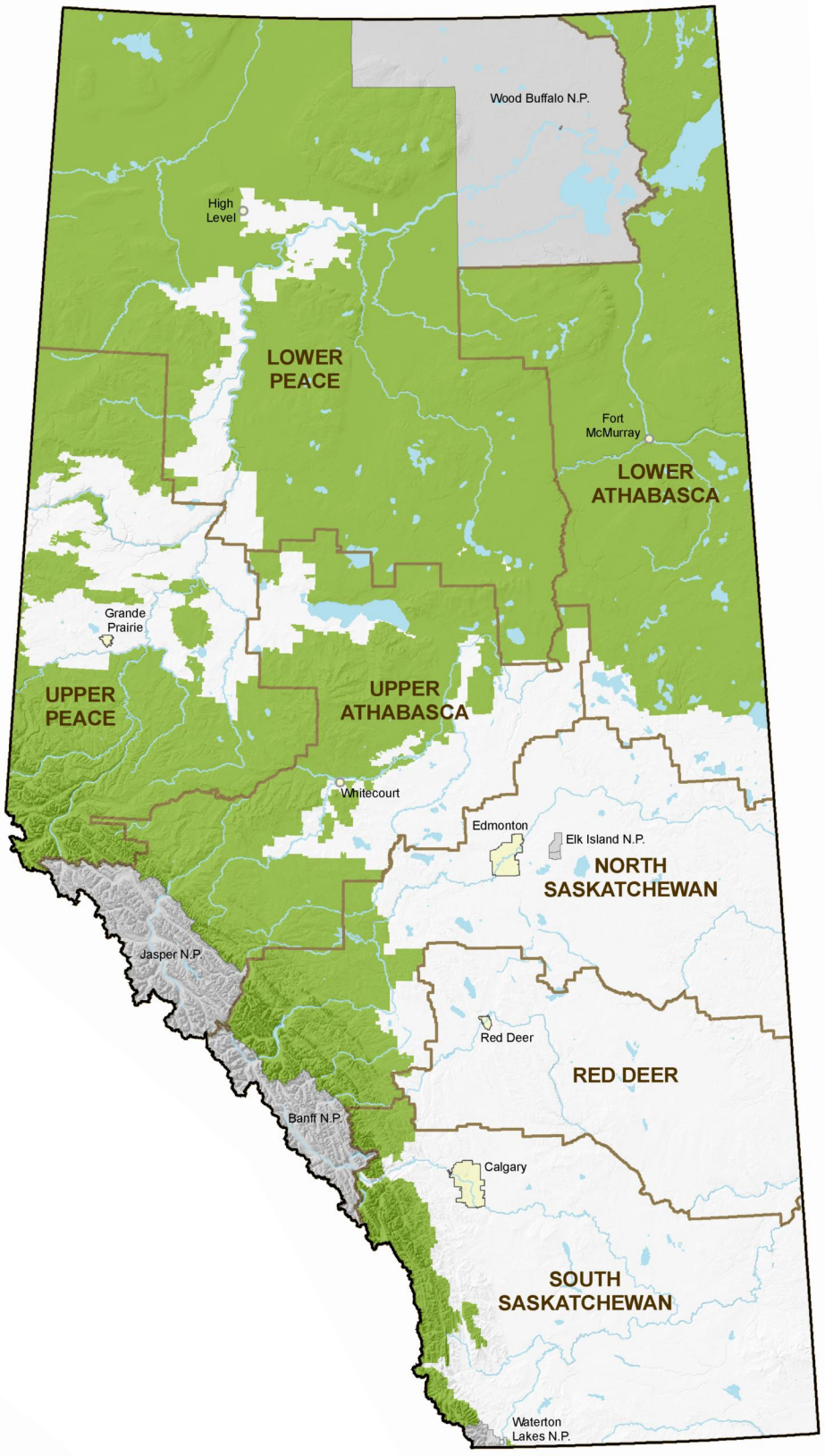
TITLE:

Location of Field Verification Sites

FILE: 11-100 PTAC.dwg

DRAWN:	JDC
CHECKED:	MT
DATE:	Jan 31/13
PROJECT:	11-100

FIGURE: **1**



Alberta

Land-use Framework Planning Regions and Green/White Management Areas

LUF Planning Regions Boundaries
Green Area
White Area
National Parks

Government of Alberta
Green/White Areas and LUF boundaries as of April 30, 2009
Produced by Sustainable Resource Development, Forestry Division, Forest Management Branch.
Base map data provided by Spatial Data Warehouse Ltd.
©2009 Government of Alberta

PROJECT:

Petroleum Technology Alliance Canada

MILLENNIUM EMS Solutions Ltd.

TITLE:

Green and White Zones of Alberta

FILE: 11-100 PTAC.dwg

DRAWN:	JDC
CHECKED:	MT
DATE:	Jan 31/13
PROJECT:	11-100

FIGURE: **2**

APPENDIX B: ROOTING DEPTH FIELD VERIFICATION METHODOLOGY

PTAC Green Zone Subsoil Project—Field Document

OBJECTIVE

The objective of this protocol is to compile a set of data regarding the maximum rooting depth of vegetative species at Green Zone sites throughout Alberta.

The primary criteria driving site selection is:

1. Site be classified as Forested Green zone/Natural Area
2. Groundwater table >2 m from surface
3. Fine-grained soil texture
4. Sites as widely distributed as possible

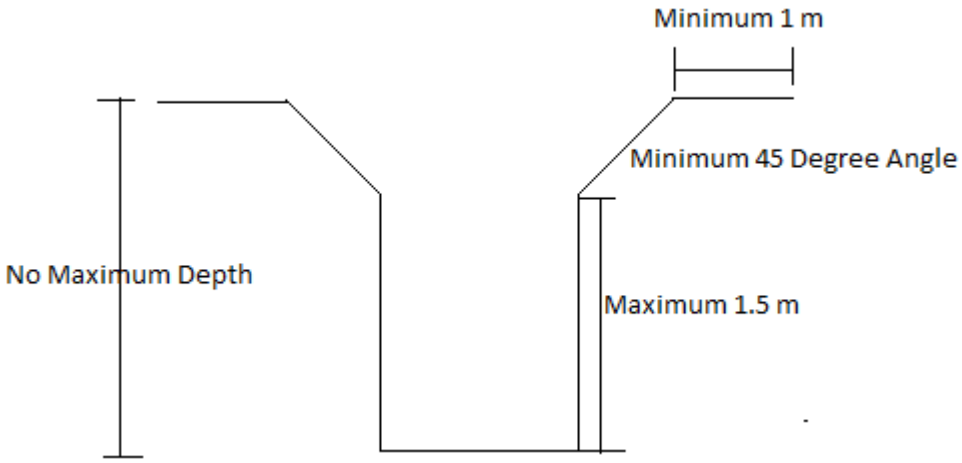
FIELD METHODOLOGY

***The following protocol should be repeated in duplicate for a given site, if possible.**

1. Make a note of the eco-site classification in which the study site is located.
2. When on-site, locate a stand of 3-5 large trees near the edge of the lease in natural vegetation (analogous to where a control would be located but still accessible by heavy equipment). It is important to choose the largest and visually healthiest trees as they will likely have the deepest maximum rooting depths.
3. Take qualitative and quantitative measurements of the trees the pit will be located adjacent too, including type, relative health, breast diameter, estimated overall height, presence of surface roots, etc. Use the supplied field sheet.
4. Using available equipment, have a trench dug as close as possible to the stand of trees in order to maximize root exposure from all tree(s) of interest. The trench should be adequate enough to occupy and at depth to identify the deepest roots (approx. 50 cm wide x 150 cm long x 150 cm deep). Have the operator construct an inclined escape ramp at one end of the trench (a safe point of entry/exit must be located no more than 8 m from the worker). Be aware of the potential for falling trees when excavating and working in the trench. Ensure the spoil pile is located at an adequate distance from the excavation to ensure it will not pose a risk of sloughing back into the excavation. A distance of at least 1 m is recommended. For further reference, please refer to MEMS SMP 17.

   If the rooting maximum is greater than 1.5 m, then the trench will need to have the walls cut back according to the following diagram:

Construction parameters for trenches >1.5 m in fine-grained/cohesive soil according to Occupational Health and Safety Code (2009).



5. Clean the face(s) of the trench. This may be done using a soil knife or using the equipment bucket/blade to scrap the face of the trench. If a trench is constructed between trees, it may be desirable to clean off both trench wall faces.
6. Provide a basic description of the soil profile using the attached field sheet. Describe as one would describe a borehole including identification and description of strata including horizon depth, color, field texture, % coarse fragments, moisture, consistence and total depth of pit. Pay particular attention to identifying any lenses of coarse soil.
7. If not already completed at Site, collect a soil sample for lab analysis (particle size analysis) from the trench face approx. 1 m below surface to verify texture (75 micron sieve).
8. Using a counting grid system, quantify the 50% total rooting depth, 80% total rooting depth, and, most importantly, the maximum depth roots are observed. For instance, if one counts 50 roots in a particular pit, determine the depth of the shallowest 25 roots for the 50% depth, the shallowest 40 roots for the 80% depth, and the deepest rooting depth for the 100% depth. ***In terms of this study, we are primarily interested in deeper rooting vegetation (tree species). Keep this in mind when calculating the % rooting depths.**
9. Identify any roots of non-tree species (forbs, grasses, shrubs, etc.). Record the number of roots by number and size as well as the root orientation and distribution. **Take photographs to illustrate root distribution.**
10. GPS the location of the trench.

***Remember, the goal of this study is to determine the maximum rooting depths of vegetation in the Green Zone of Alberta.**

PTAC Green Zone Subsoil Rooting Project

Trench ID _____ **Assessor** _____ **Date** _____

Legal Location _____ **GPS Location** _____

Ecosite _____ **Photograph ID** _____

VEGETATION ASSESSMENT

Stand/Plot Information	Tree Type	Tree Vigour/Health	Tree Height	Tree Breast Circumference	Surface Rooting	General Comments

SOIL ASSESSMENT

Pit Information	Horizon and / or Depth	Field Texture	Colour	Moisture	Consistence	General Comments

ROOT ASSESSMENT							
Stand/Plot Information	**Total Root Number**	**50% Rooting Depth**	**80% Rooting Depth**	**Maximum Rooting Depth**	***General Root Size/Abundance/Orientation**		
					50% Rooting Depth	**80% Rooting Depth**	**Maximum Rooting Depth**
Deep Rooting Vegetation (Trees)							
Shallow Rooting Vegetation (Grasses, Shrubs)							

* Terminology for deciphering root size/abundance			
vf=very fine	f=fine	vf = very few	f = few
h=horizontal	v=vertical	m=medium	c=coarse
i=inped	e = exped	c = common	m = many

Rooting Comments/Sketch

Please sketch the trench face and describe rooting depths, patterns, orientation, distribution, matting, or any other relevant features.

APPENDIX C: ROOTING DEPTH FIELD DATA SUMMARY

Date: **Oct. 7, 2010**

MEMS File No.: **10-003**

Assessor: **Johan Jensen**

Site #: **1**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (H1), dominant vegetation in the area will include white and black spruce as well as paper birch. On-site tree and shrub species consisted of paper birch, alder and willow.

Water Table Information:

According to data collected from a groundwater monitoring event conducted on the Site in December 2010, groundwater levels ranged from 1.17 m to 10.23 m below ground surface (bgs). Borehole logs indicate wet conditions were encountered as shallow as 1.5 m. Peaty/organic topsoil horizons indicate wet surface conditions.

Soil Stratigraphy and Characteristics:

Located in the Gray and Dark Gray Soil Zones of the North Peace area. Predominant soils include Dark Gray and Gray Luvisols with minor inclusions of Solonetzic, Gleysolic and Organic soils. Soil texture was determined to be fine-grained through lab analysis.

Rooting Assessment:

- Maximum Rooting Depth:

  Betula papyrifera Marsh. (Paper birch) – Height 15 m; **Maximum rooting depth of 0.65 m**
  *Salix L. (*Willow) -- Maximum **rooting depth of 0.5 m**
  *Alnus Crispa (*Ait.) Pursh. (Green Alder) – **Maximum rooting depth 0.58 m**

Overall Root Characteristics:

Majority of roots were developed within 0.3 m of surface. Below 0.3 m to the maximum rooting depth, roots were noted to be low in numbers and very fine.

Date: **Oct. 6, 2010**

MEMS File No.: **10-004**

Assessor: **Johan Jensen**

Site #: **2**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (C1), dominant vegetation in the area will include two-tiered canopies of jack pine and black spruce, with an understorey dominated by Labrador tea and bog cranberry. Vegetation noted on-site included jack pine, black and white spruce and aspen.

Water Table Information:

According to data collected from a groundwater monitoring event conducted on the Site in December 2010, groundwater levels ranged from 1.32 m to 5.92 m bgs in background nested wells. Borehole logs indicate generally moist conditions from surface to the completion of the boreholes. Peaty/organic topsoil horizons in a number of boreholes indicate wet surface conditions.

Soil Stratigraphy and Characteristics:

Located in the Gray and Dark Gray Soil Zones of the North Peace area. Predominant soils include Dark Gray and Gray Luvisols with minor inclusions of Solonetzic, Gleysolic and Organic soils. Soil texture was determined to be fine-grained through lab analysis.

Rooting Assessment:

- Maximum Rooting Depth:

  Pinus banksiana Lamb. (Jack Pine) – Height 20 m; **Maximum rooting depth of 1.30 m (taproot)**

  Picea mariana (Mill.) BSP. (Black Spruce) - Height 4 m; **Maximum rooting depth of 0.38 m**

  Picea glauca (Moench) Voss (White Spruce) - Height 4 m; **Maximum rooting depth of 0.55 m**

  Populus tremuloides Michx. (Aspen) – **Maximum rooting depth of 0.25 m**

Overall Root Characteristics:

Only the tap root of the jack pine reached 1.3 m. Majority of roots were developed within 0.3 to 0.4 m of surface. Below 0.3 m, roots were noted to be low in numbers and very fine. No fibrous roots were noted.

Date: **Oct. 6, 2010**

MEMS File No.: **10-005**

Assessor: **Johan Jensen**

Site #: **3**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (D1), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. A Phase 2 ESA of the site indicates on-site vegetation consists of poplar, birch and willow.

Water Table Information:

According to data collected from a groundwater monitoring event conducted at the site in June 2010, groundwater levels ranged from 0.29 m to 5.64 m bgs in background wells. Borehole logs indicate generally moist conditions from surface to the completion of the boreholes with wet conditions encountered as shallow as 0.4 m. Peaty/organic topsoil horizons in a number of boreholes indicate wet surface conditions.

Soil Stratigraphy and Characteristics:

Located in the Gray and Dark Gray Soil Zones of the North Peace area. Predominant soils include Dark Gray and Gray Luvisols with minor inclusions of Solonetzic, Gleysolic and Organic soils. Soil texture was determined to be fine-grained through lab analysis.

Rooting Assessment:

- Maximum Rooting Depth:

  *Alnus Crispa (*Ait.) Pursh. (Green Alder) – Height 7 m; **Maximum rooting depth of 0.64 m**
  *Salix L. (*Willow) – Height 6 m; **Maximum rooting depth of 0.55 m**

Overall Root Characteristics:

Majority of roots were developed within 0.3 to 0.5 m of surface. Below 0.3 m, roots were noted to be lower in numbers and fine to very fine in terms of physical stature. Fibrous roots were also noted to a maximum depth of 0.52 m. These roots reflect the presence of shrubby vegetation.

Date: **Oct. 6, 2010**

MEMS File No.: **10-006**

Assessor: **Johan Jensen**

Site #: **4**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (D1), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. A Phase 2 ESA of the site indicates on-site vegetation consists of poplar, birch, white spruce and willow.

Water Table Information:

Groundwater levels were monitored on-site on June 1, 2010. Recorded groundwater levels ranged from 0.2 m to 5.44 m bgs. Borehole logs indicate generally moist conditions from surface to the completion of the boreholes with wet conditions encountered as shallow as 1.1 m at one location. Peaty/organic topsoil horizons in a number of boreholes indicate wet surface conditions.

Soil Stratigraphy and Characteristics:

Located in the Gray and Dark Gray Soil Zones of the North Peace area. Predominant soils include Dark Gray and Gray Luvisols with minor inclusions of Solonetzic, Gleysolic and Organic soils. Soil texture was determined to be fine-grained through lab analysis.

Rooting Assessment:

- Maximum Rooting Depth:

  *Salix L. (*Willow) – Height 5 m; **Maximum rooting depth of 0.65 m**

  Populus tremuloides Michx. (Aspen) – Height 8 m; **Maximum rooting depth of 0.6 m**

  Picea glauca (Moench) Voss (White Spruce) - **Maximum rooting depth of 0.4 m**

Overall Root Characteristics:

Majority of roots were developed within 0.3 m of surface. Below 0.3 m, roots were lower in numbers and fine to very fine in terms of physical stature. Fibrous roots were also noted to a maximum depth of 0.5 m and followed similar orientation/physical stature patterns as the assessed tree roots.

Date: **Oct. 7, 2010**

MEMS File No.: **10-021**

Assessor: **Johan Jensen**

Site #: **5**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (D1), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. For this location, on-site tree species was limited to aspen alone.

Water Table Information:

During the groundwater monitoring event completed December 5th through 9th, 2010, the recorded shallow groundwater levels ranged from 1.87 m to 4.39 m bgs. Borehole logs indicate generally moist conditions from surface to the completion of the boreholes with wet conditions encountered as shallow as 1.0 to 1.1 m at two locations. Wet conditions were not encountered in control locations. Peaty/organic topsoil horizons in a number of boreholes indicate wet surface conditions.

Soil Stratigraphy and Characteristics:

From the Phase 2 ESA, general lithology on-site consisted of admixed clay to silty clay overlying fine-grained clay. Fine to coarse sand seams less than 10 cm were noted at three assessment locations; however, evidence supporting the use of coarse-grained guidelines was lacking as sand lenses were not consistent between boreholes and across the Site. Beneath this, the main subsoil unit consisted of fine-grained clay till.

Rooting Assessment:

- Maximum Rooting Depth:

  Populus tremuloides Michx. (Aspen) – **Maximum rooting depth of 1.0 m**

Overall Root Characteristics:

The majority of roots were developed within 0.6 m of the surface. Below 0.3 m, roots were lower in numbers and fine to very fine in terms of physical stature. Fibrous roots were also noted **to a maximum depth of 1.5 m** and followed similar orientation/physical stature patterns as the assessed tree roots with the majority of fibrous roots occurring within the 0.5 m of the surface.

Date: **Oct. 7, 2010**

MEMS File No.: **10-129**

Assessor: **Johan Jensen**

Site #: **6**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (D1), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. For this location, on-site tree species included aspen and white spruce.

Water Table Information:

During the groundwater monitoring event completed December 7th, 2010, the recorded shallow groundwater levels ranged from 1.97 m to 3.17 m bgs. Borehole logs indicate generally dry to moist conditions from surface to 1.0 m followed by moist conditions to the completion of the boreholes. No wet conditions were encountered.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of admixed clay to silty clay overlying fine-grained clay. Beneath this, the main subsoil unit consisted of fine-grained clay till. Located in the Gray and Dark Gray Soil Zones of the North Peace area, predominant soils include Dark Gray and Gray Luvisols with minor inclusions of Solonetzic, Gleysolic and Organic soils. Soil texture was determined to be fine-grained through lab analysis.

Rooting Assessment:

- Maximum Rooting Depth:

  Populus tremuloides Michx. (Aspen) – Height 15 m; **Maximum rooting depth of 0.75 m**

  Picea glauca (Moench) Voss (White Spruce) – Height 9 m; **Maximum rooting depth of 0.75 m**

Overall Root Characteristics:

The majority of roots were developed within 0.2 m of the surface. Below 0.3 m, roots were lower in numbers and fine to very fine in terms of physical stature. Fibrous roots were also noted to a maximum depth of 0.63 m and followed similar orientation/physical stature patterns as the assessed tree roots with the majority of fibrous roots occurring within the 0.3 m of the surface.

Date: **Oct. 7, 2010**

MEMS File No.: **10-128**

Assessor: **Johan Jensen**

Site #: **7**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal ecoregion. According to the eco-site classification (D1), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. For this location, on-site tree species included paper birch and white spruce.

Water Table Information:

According to borehole logs collected during a Phase 2 ESA of the Site, generally moist conditions extend from the surface to the completion of the borehole. However, no wet conditions were encountered at any location.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of brown admixed clay with some coarse fragments. Beneath this, the main subsoil unit consisted of fine grained clay loam overlying clay till. The soil texture was determined to be fine grained based on particle size analysis and soil profiles.

Rooting Assessment:

- Maximum Rooting Depth:

  Betula papyrifera Marsh. (Paper Birch) – Height 10 m; **Maximum rooting depth of 0.75 m.**

  Picea glauca (Moench) Voss (White Spruce) – Height 10 m; **Maximum rooting depth 0.65 m**

Overall Root Characteristics:

The majority of roots were developed within 0.3 m of the surface. Below 0.3 m, roots were lower in numbers and fine to very fine in terms of physical stature. Fibrous roots were also noted to a maximum depth of 0.7 m and followed similar orientation/physical stature patterns as the assessed tree roots with the majority of fibrous roots occurring within the 0.3 m of the surface.

Date: **Jan. 30, 2012**

MEMS File No.: **08-1220**

Assessor: **Cory Kartz**

Site #: **8**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the upper foothills sub eco-region. According to the eco-region classification, the site will be dominated by lodgepole pine, white and black spruce, as well as sub-alpine fir. It was noted during the site visit that spruce and pine species were the dominant natural tree species. Little or no shrubbery/grasses were noted on-site. Vegetation assessed on-site was limited to lodgepole pine.

Water Table Information:

According to GW monitoring events in 2010, the GW level ranged from 1.9 to 3.4 m below top of casing (BTOC). During the rooting depth study, generally moist conditions were encountered to the pit completion depth of 1.4 m. No wet conditions or seeping water were observed.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of FH (0.24 – 0 m) overlying 0.12 m of black-brown moist clay loam topsoil. Beneath the top soil, moist brown clay loam extended to 0.27 m followed by moist light brown silty clay to 0.47 m. Moist, light brown silty clay was then observed to the completion of the pit at 1.4 m. The soil texture was determined to be fine grained based on particle size analysis and soil profiles from the Phase 2 ESA.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 15 m, Breast Circumference 0.82 m; **Maximum rooting depth of 0.80 m.**
  2) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 14 m, Breast Circumference 0.70 m; **Maximum rooting depth of 0.90 m.**

Overall Root Characteristics:

For Trees 1 and 2 assessed, the 50 % rooting depths were 0.35 and 0.40 m, and 80% rooting depths were 0.54 and 0.67 m, respectively. Generally, the 50% rooting depth consisted of common coarse to medium sized roots extending in a horizontal plane. The maximum rooting depth consisted of very

few fine to very fine horizontal roots. There was no observable shallow rooting vegetation adjacent to the pit though observations around the site found shallow rooting orientation to stay within the FH and upper topsoil layers.

Date: **Feb. 24, 2012**

MEMS File No.: **09-1381**

Assessor: **Cory Kartz**

Site #: **9**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Assessed under Natural land use

Site Vegetation:

The Site is located in the upper foothills sub eco-region. According to the eco-region classification, the Site will be dominated by lodgepole pine, white and black spruce, as well as sub-alpine fir. It was noted during the site visit that pine, spruce and poplar species were the dominant natural tree species. Woody shrubbery dominated the understorey. Vegetation assessed on-site was limited to lodgepole pine.

Water Table Information:

During the rooting depth study, generally moist conditions were encountered to the pit completion depth of 1.5 m. No wet conditions or seeping water were observed though conditions were quite moist. No water table information pertaining to the Site was available for review. A prior Phase 2 ESA completed on the Site, however, noted generally moist conditions in the majority of boreholes.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of LFH (0.14 to 0 m) overlying 0.12 m of brown dry sandy loam to sandy clay loam topsoil. Beneath the top soil, dry light grey sandy clay loam extended to 0.18 m followed by moist dark brown clay loam to 0.64 m. Moist dark brown to grey clay loam/till was then observed to the completion of the pit at 1.5 m. Extensive mottling was noted at 0.18 m below surface. The soil texture was determined to be fine grained based on particle size analysis and soil profiles from the Phase 2 ESA.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 18 to 22 m, Breast Circumference 1.43 m; **Maximum rooting depth of 1.0 m.**

Overall Root Characteristics:

The 50% and 80% rooting depths were 0.36 and 0.63 m, respectively. Generally, the 50% rooting depth consisted of medium to coarse abundant roots extending in a horizontal plane. The maximum

rooting depth consisted of very few very fine horizontal roots. A clear border for tree roots was evident at 0.8 m. Shallow rooting vegetation around the pit consisted of smaller saplings and woody shrubs. The root orientation of these shallow rooting vegetation species was determined to stay within the LFH and upper topsoil layers.

Date: **Feb. 24, 2012**

MEMS File No.: **09-1296**

Assessor: **Cory Kartz**

Site #: **10**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the upper foothills sub eco-region. According to the eco-region classification, the Site will be dominated by lodgepole pine, white and black spruce, as well as sub-alpine fir. It was noted during the site visit that pine was the dominant natural tree species. Little or no shrubbery/grasses were noted on-site due to snow cover. Vegetation assessed on-site was limited to lodgepole pine.

Water Table Information:

No previous groundwater monitoring events at the Site were available for review. During the rooting depth study, generally dry to moist conditions were encountered to the pit completion depths of 1.65 and 1.75 m. No wet conditions or seeping water were observed in either pit.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of FH (0.22 to 0 m) overlying 0.12 m of light brown to red-brown dry sandy to silty loam topsoil. Beneath the top soil, dry light brown to grey silt to silty loam extended to 0.24 m followed by moist dark grey to brown clay loam to 0.65 m. Moist dark brown to grey clay till was then observed to the completion of the pits at 1.65 to 1.75 m. The soil texture was determined to be fine grained based on field observation.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 18 m, Breast Circumference 0.75 m; **Maximum rooting depth of 1.2 m.**
  2) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 14 m, Breast Circumference 0.53 m; **Maximum rooting depth of 1.15 m.**
  3) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 17 m, Breast Circumference 0.73 m; **Maximum rooting depth of 1.4 m.**

Overall Root Characteristics:

The maximum rooting depth of each tree was measured to the top of the LFH layer. For the three trees, the 50% rooting depth consisted of medium to coarse abundant roots in both the horizontal and vertical planes. The 80% rooting depth consisted of fine to medium few to plentiful horizontal roots. Only very fine very few (<5) roots were seen at the maximum depth for all trees assessed. It was not possible to confirm whether the observed deepest roots were attached to actively growing vegetation.

Date: **Feb. 23, 2012**

MEMS File No.: **07-1182**

Assessor: **Cory Kartz**

Site #: **11**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located on the border of the upper foothills and sub-alpine sub eco-regions. According to the eco-region classification, the Site will be dominated by lodgepole pine, spruce, as well as sub-alpine fir. It was noted during the site visit that spruce and pine were the dominant natural tree species. Little or no shrubbery/grasses were noted on-site due to snow cover.

Water Table Information:

A groundwater monitoring event in 2012 identified a water table at 9.0 m bgl. During the rooting depth study, generally dry to moist conditions were encountered to the pit completion depths of 1.5 m. No wet conditions or seeping water were observed in either pit.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of FH overlying dry light brown sandy clay loam topsoil. Beneath the top soil, dry brown sandy clay loam was observed overlying dry grey clay till to the completion of the pits at 1.5 m. An increase in gravel-sized coarse fragments was noted at 0.8 m. The soil texture was determined to be fine grained based on particle-size analysis data collected during a previous Phase 2 ESA.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 20 to 25 m, Breast Circumference 0.85 m; **Maximum rooting depth of 1.2 m.**
  2) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 20 to 25 m, Breast Circumference 0.90 m; **Maximum rooting depth of 1.1 m.**
  3) *Picea mariana* (Mill.) BSP. (Black Spruce)– Height 25 to 30 m, Breast Circumference 1.40 m; **Maximum rooting depth of 1.2m.**

Overall Root Characteristics:

The maximum rooting depth of each tree was measured to the top of the FH layer. The 50% rooting depth consisted of medium to coarse plentiful to abundant roots in the horizontal plane. The 80% rooting depth for the pine trees consisted of fine to medium plentiful horizontal roots; the spruce tree displayed a few medium to coarse horizontal and vertical rooting pattern. The vast majority of observable roots were above 0.7 to 0.8 m for all three trees assessed. Only very fine very few (<2) roots were seen at maximum depth. It was not possible to confirm whether the observed deepest roots were attached to actively growing vegetation.

Date: **Feb. 2, 2012**

MEMS File No.: **09-1284**

Assessor: **Lonnie Sweet**

Site #: **12**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the upper foothills sub eco-region. According to the eco-region classification, the Site will be dominated by lodgepole pine, white and black spruce, as well as sub-alpine fir. It was noted during the site visit that spruce was the dominant natural tree species.

Water Table Information:

A groundwater monitoring event in 2010 identified a water table ranging between 2.31 and 2.8 m bgl.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of sandy to silty clay from surface to 0.3 m bgl overlying sandy clay from 0.3 to 1.2 m. Sandy clay with gravel and cobbles was observed from 1.2 m to the completion of the three pits at 1.5 m. Soil texture on Site was determined to consist of both fine and coarse-grained soils based on particle size analysis and soil profiles from a previous Phase 2 ESA completed on-site

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Picea mariana* (Mill.) BSP. (Black Spruce) - **Maximum rooting depth of 0.5 to 0.6 m.**
  2) *Picea mariana* (Mill.) BSP. (Black Spruce) - **Maximum rooting depth of 0.5 to 0.6 m.**
  3) *Picea mariana* (Mill.) BSP. (Black Spruce) - **Maximum rooting depth of 0.5 to 0.6 m.**

Overall Root Characteristics:

The 50% rooting depth for all three trees was observed to be 0.3 m and the 80% rooting depth was observed to be approximately 0.45 m.

Date: **Feb. 23, 2012**

MEMS File No.: **NWLR**

Assessor: **Derek Flewell**

Site #: **13**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located within the central mixedwood sub eco-region. According to the eco-region classification, the Site will be dominated by aspen, black and white spruce. It was noted during the site visit that poplar and pine were the dominant natural tree species.

Water Table Information:

During the rooting depth study, generally moist conditions were encountered to the pit completion depths of 1.5 m. No wet conditions or seeping water were observed in either of the two assessed pits.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of brown to black moist topsoil to 0.3 m overlying moist brown silty clay to 1.5 m. The soil texture was determined to be fine grained based on field texturing.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Populus tremuloides* Michx. (Aspen) – Height 24 m, Breast Circumference 1.2 m; **Maximum rooting depth of 0.3 m.**
  2) *Populus tremuloides* Michx. (Aspen) – Height 24 m, Breast Circumference 1.2 m; **Maximum rooting depth of 0.3 m.**
  3) *Populus tremuloides* Michx. (Aspen) – Height 24 m, Breast Circumference 0.9 m; **Maximum rooting depth of 0.3 m.**
  4) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 18 m, Breast Circumference 0.9 m; **Maximum rooting depth of 0.3 m.**
  5) *Pinus contorta var. latifolia* Loudon (Lodgepole Pine) – Height 24 m, Breast Circumference 0.9 m; **Maximum rooting depth of 0.3 m.**

Overall Root Characteristics:

The 50% rooting depth consisted of few coarse roots in the horizontal plane. The 80% rooting depth consisted of few coarse horizontal roots. During the survey, it was noted that the larger tree roots

followed the horizon between the topsoil and lower clay horizon and did not extend further than 0.05 m into the clay.

Date: **Mar. 9, 2012**

MEMS File No.: **06-1048**

Assessor: **Drew Lockwood**

Site #: **14**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Assessed under Agricultural land use

Site Vegetation:

The Site is located within the dry mixedwood sub eco-region. According to the eco-region classification, the Site will be dominated by aspen and white spruce. It was noted during the site visit that poplar was identified as the dominant natural tree species.

Water Table Information:

A previous Phase 2 ESA completed on the Site identified a water table varying between 1.66 and 4.02 m bgs. During the rooting depth study, generally moist conditions were encountered to the pit completion depths of 1.5 m. No wet conditions or seeping water were observed in either pit.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of brown moist silt loam topsoil to 0.16 m overlying moist brown clay to 0.55 m. A dark brown C horizon completed the pit to a depth of 1.5 m. The soil texture was determined to be fine-grained based on field texturing and particle size analysis.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Populus balsamifera* L. (Balsam poplar) – Height 13 m, Breast Circumference 0.75 m; **Maximum rooting depth of 0.9 m.**
  2) *Populus balsamifera* L. (Balsam poplar)– Height 12 m, Breast Circumference 0.71 m; **Maximum rooting depth of 0.9 m.**

Overall Root Characteristics:

The 50% rooting depth consisted of abundant medium to coarse roots in the horizontal plane. The 80% rooting depth consisted of plentiful fine to medium horizontal roots. The maximum rooting depth featured a few medium horizontal roots.

Date: **July 18, 2012**

MEMS File No.: **11-232/233**

Assessor: **V. Lyzhin, J. Kaufmann**

Site #: **15**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Central Mixedwood Boreal eco-region. According to the eco-site classification (D2), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. At the time of assessment, black spruce was noted in a transitional area between a D2 and G1 eco-site.

Water Table Information:

During the rooting depth study, generally moist conditions were encountered to the pit completion depths of 1.5 m. Of the three pits assessed, wet conditions were observed in a single pit from surface to 1.0 m. No wet or seeping conditions were noted in any of the three pits below 1.0 m.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of brown to dark brown moist to wet silt loam to sandy loam topsoil to approximately 0.11 m overlying moist to wet brown silty clay loam to sandy clay loam to 0.30 to 0.46 m. A dark brown clay loam to clay BC or C horizon completed the pits to a depth of 1.5 m. The soil texture was determined to be fine grained based on field texturing and particle size analysis.

Rooting Assessment:

- Maximum Rooting Depth:
  1) *Populus tremuloides* Michx. (Aspen) – Height 18 m, Breast Circumference 0.94 m; **Maximum rooting depth of 1.24 m.**
  2) *Picea mariana* (Mill.) BSP. (Black Spruce) - Height 16 m, Breast Circumference 0.64 m; **Maximum rooting depth of 0.94 m.**
  3) *Populus tremuloides* Michx. (Aspen) – Height 17 m, Breast Circumference 0.56 m; **Maximum rooting depth of 1.05 m.**

Overall Root Characteristics:

The 50% rooting depth consisted of abundant medium to coarse roots in the horizontal plane. The 80% rooting depth consisted of plentiful coarse horizontal and vertical roots. The maximum rooting depth featured a few medium horizontal and vertical roots.

Date: **July 31, 2012**

MEMS File No.: **11-033**

Assessor: **J. Jensen, P. Martin**

Site #: **16**

PTAC Rooting Zone Study
Site Summary Sheet

Site Physiography

Land Use: Natural/Green Zone

Site Vegetation:

The Site is located in the Dry Mixedwood Boreal eco-region. According to the eco-site classification (D2), dominant vegetation in the area will include aspen, with some balsam poplar and paper birch, and relatively few, if any, white spruce. At the time of assessment the dominant vegetation in the study area included aspen, white spruce, alder and willow.

Water Table Information:

During the rooting depth study, generally moist conditions were encountered to the pit completion depths of 1.5 m. No wet or seeping conditions were encountered to a depth of 1.5 m.

Soil Stratigraphy and Characteristics:

General lithology on-site consisted of sandy loam topsoil to approximately 0.14 m overlying sandy clay loam to 0.26 m. Firm clay loam was then encountered to a depth of 0.74 m. From 0.74 m to 1.01 m a sandy clay loam BC layer was observed followed by a massive sandy clay loam C horizon to the completion of the borehole at 1.5 m. The soil texture was determined to be fine grained based on field texturing.

Rooting Assessment:

Maximum Rooting Depth:

1) *Populus tremuloides* Michx. (Aspen) – Height 21 m, Breast Circumference 1.23 m; **Maximum rooting depth of 1.38 m.**

Overall Root Characteristics:

The 50% rooting depth consisted of abundant fine to coarse roots in the horizontal or random plane. The 80% rooting depth consisted of abundant fine to coarse horizontal and random roots.

APPENDIX D: MILLENNIUM EMS SOLUTIONS LTD. THIRD PARTY RELIANCE AGREEMENT

Professional Services Agreement
Third Party Reliance

This Document is intended for Third Parties wishing to rely on the information contained within this report.

PARTIES
This Agreement made this ___ day of _____ between:

and **Millennium EMS Solutions Ltd.**
6111 – 91st Street
Edmonton AB
T6E 6V6

Attn.:

Attn: Steve Ferner

hereinafter called "THIRD PARTY"

hereinafter called "MILLENNIUM"

THIRD PARTY engages MILLENNIUM to provide a right of reliance to the THIRD PARTY in connection with Millennium report entitled **"Proposed Exclusion Depths for the Ecological Direct Contact Exposure Pathway at Remote Alberta Green Zone Sites"**

SCOPE OF SERVICES
MILLENNIUM agrees to allow the THIRD PARTY to rely on information presented within this report.

COMPENSATION
THIRD PARTY agrees to compensate MILLENNIUM for $1.00 for right to rely on the information, the receipt of which is acknowledged.

TERMS AND CONDITIONS

1. EXTENT OF AGREEMENT. This Agreement represents the entire agreement between MILLENNIUM and THIRD PARTY and supersedes all prior negotiations, representations, or agreements, either written or oral. This Agreement may be altered only by written instrument signed by authorized representatives of both THIRD PARTY and MILLENNIUM.
2. STANDARD OF CARE. MILLENNIUM shall perform its services in a manner consistent with the standard of care and skill ordinarily exercised by members of the profession practicing under similar conditions in the geographic vicinity and at the time the services are performed. This Agreement neither makes nor intends a warranty or guarantee, express or implied.
3. INDEMNITY. THIRD PARTY waives any claim against MILLENNIUM, its officers, employees and agents and agrees to defend, indemnify, protect and hold harmless MILLENNIUM and its officers, employees and agents from any and all claims, liabilities, damages or expenses, including but not limited to delay of the project, reduction of property value, fear of or actual exposure to or release of toxic or hazardous substances, and any consequential damages of whatever nature, which may arise directly or indirectly, to any party, as a result of the services provided by MILLENNIUM under this Agreement, unless such injury or loss is caused by the sole negligence of MILLENNIUM. All claims by THIRD PARTY shall be deemed relinquished unless filed within one (1) year after substantial completion of the services.
4. LIMITATION OF LIABILITY. Notwithstanding any other provision of this Agreement, THIRD PARTY agrees to limit MILLENNIUM's and its officers, employees and agents liability due to professional negligence and to any liability arising out of or relating to this Agreement to $5,000. This limit applies to all services on this project, whether provided under this or subsequent agreements, unless modified in writing, agreed to and signed by authorized representatives of the parties. In addition, MILLENNIUM shall not be liable for consequential, incidental or indirect damages as a result of the performance of this Agreement.
5. RESPONSIBILITY. MILLENNIUM is not responsible for the completion or quality of work that is dependent upon or performed by the THIRD PARTY or third parties not under the direct control of MILLENNIUM, nor is MILLENNIUM responsible for their acts or omissions or for any damages resulting there from.
6. EXCLUSIVE USE. Services provided under this Agreement, including all reports, information or recommendations prepared or issued by MILLENNIUM, are for the exclusive use of the THIRD PARTY for the project specified. No other use is authorized under this Agreement. THIRD PARTY releases MILLENNIUM from liability and agrees to defend, indemnify, protect and hold harmless MILLENNIUM from any and all claims, liabilities, damages or expenses arising, in whole or in part, from such unauthorized distribution.
7. We disclaim any undertaking or obligation to advise Third Party or modify this opinion to reflect changes which may come or be brought to our attention.

THIRD PARTY acknowledges that they have read and agree to the Terms and Conditions attached to this document which are incorporated herein and made a part of this Agreement.

Third Party:

By: _____

Title: _____

Date: _____