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

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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

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- 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,

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7.0 REFERENCES

Adams, W.R. and Chapman, G.L. 1941. Competition influence on the root systems of jack and Norway pines. Vermont Agricultural Experimental Station Bulletin. 472, 32 pp.

AENV (Alberta Environment). 2010. Alberta Tier 1 Soil and Groundwater Remediation Guidelines. December 2010.

Alberta (Government of Alberta). 2006. Natural Regions and Subregions of Alberta. Compiled by D.J. Downing and W.W. Pettapiece. Alberta Natural Regions Committee. Government of Alberta. Pub. No. T/852.

Bannan,, M.W. 1940. The Root Systems of Northern Ontario Conifers Growing in Sand. American Journal of Botany 27(2): 108-114.

Bishop, D.M. 1962. Lodgepole pine rooting habits in the blue mountains of northeastern Oregon. Ecology 43(1): 140-142.

Bockheim, J.G., O'Brien, J.D., Munroe, J.S., and Hinkel, K.M. 2003. Factors Affecting the Distribution of *Populus balsamifera* on the North Slope of Alaska, U.S.A. Arctic, Antarctic, and Alpine Research 35(3): 331–340.

Burns, R.M., Honkala, B.H. 1990a. Silvics of North America: vol. 1. Conifers. US Department of Agriculture, Washington, DC. Agricultural. Handbook no. 654.

Burns, R.M., Honkala, B.H. 1990b. Silvics of North America: vol. 2. Hardwoods. US Department of Agriculture, Washington, DC. Agricultural Handbook no. 654.

Canadell, J., Jackson, R.B., Ehleringer, J.R. et al. 1996. Maximum rooting depth of vegetation types at the global scale. Oecologia 108: 583-595.

Evans, R., Cassel, D.K., and Sneed, R.E. 1996. Soil, water, and crop characteristics important to irrigation scheduling. North Carolina Cooperative Extension Service, AG452-1. Consulted online at: http://www.bae.ncsu.edu/programs/extension/evans/ag452-1.html

FAO (Food and Agriculture Organization). 1978. Effective Rainfall in Irrigated Agriculture. Series title: FAO Irrigation and Drainage Papers - 25. Ref: X5560/E. ISBN 92-5-100272-X.

Fierer, N., Schimel, J.P., and Holden, P.A. 2003. Variations in microbial community composition through two soil depth profiles. Soil Biology and Biochemistry 35, 167-176.

Horton KW. 1958. Rooting habits of lodgepole pine (Forest Research Division technical note 67). Canadian Department of Northern Affairs and Natural Resources.

Johnston, R.S. 1975. Soil water depletion by Iodgepole pine on glacial till. US Department of Agriculture - Forest Service. Note INT-199.

Karim, M.N., and Mallik, A.U. 2008. Roadside revegetation by native plants i. Roadside microhabitats, floristic zonation and species traits. Ecological Engineering 32: 222-237.

Kramer, S., Miller, P.M., and Eddleman, L.E. 1996. Root system morphology and development of seedling and juvenile *Juniperus occidentalis*. Forest Ecology and Management 86: 229-240.

Mundell, T.L., Landhausser, S.M., and Lieffer, V.J. 2007. Effects of *Corylus cornuta* stem density on root suckering and rooting depth of *Populus tremuloides*. Canadian Journal of Botany 85: 1041–1045.

Nicholl, B.C., Gardiner, B.A., Rayner, B., and Peace, A.J. 2006. Anchorage of coniferous trees in relation to species, soil type and rooting depth. Canadian Journal of Forest Research 36: 1871-1883.

Simmons, M.E., Brotherson, J.D., and Monsen, S.B. 2000. Rooting habits of lodgepole pine (*Pinus contorta*) in relation to soil characteristics on copper-cobalt mine spoils. 2000 Billings Land Reclamation Symposium.

Startsev, A., and Battigelli, J. 2008. Validation of the subsoil PHC criteria for stratified remediation of upstream oil and gas facilities. Presentation at the 2008 Petroleum Technology Alliance Canada (PTAC) Soil and Groundwater Forum, Calgary, March 10, 2008.

Startsev, A., and Battigelli, J. 2010. Alberta's stratified approach to soil remediation: validating critical values for PHC fractions in subsoil based on their lacking effect on crops and invertebrates. Presentation at the 2010 Petroleum Technology Alliance Canada (PTAC) Soil and Groundwater Forum, Calgary, March 15, 2010.

Strong, W.L., and La Roi, G.H. 1983. Root-system morphology of common boreal forest trees in Alberta, Canada. Canadian Journal of Forest Research 13(6): 1164–1173.

Titus, B.D., Roberts, B.A., and Deering, K.W. 1998. Nutrient removals with harvesting and by deep percolation from white birch (*Betula papyrifera* [Marsh.]) sites in central Newfoundland. Canadian Journal of Soil Science 78(1): 127-137.

USFS (United States Forest Service). 2009. Graminoid database. Consulted online November 2, 2009. http://www.fs.fed.us/database/feis/plants/graminoid/