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Agronomic Receptor Evaluation for Direct Soil Contact

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Table of Contents

List of Tables (in Text)

List of Figures (in Text)

1.0 INTRODUCTION

The ecological direct contact pathway for terrestrial plants and invertebrates applies across all land-use designations (AEP 2016a). At the Federal level, the Canadian Council of Ministers of the Environment (CCME) have decided that this pathway is applicable to all soils above 1.5 m, and established that the pathway need not be applied to soils deeper than 3.0 m (CCME 2008). The CCME has left soils at intermediate depths (between 1.5 and 3.0 m), to the governing jurisdiction to make a ruling.

In Alberta, there are several guidance documents that specifically reference the operative depth of the ecological direct contact pathway:

- Alberta Environment and Parks (AEP) *Tier 1 and Tier 2 Soil and Groundwater Guidelines* (2016a, b):
  - Applies to all land uses and governs by depth;
  - The ecological direct contact pathway may be eliminated at depths exceeding 3.0 meters, if an alternative guideline is available (*i.e.,* management limit), which currently applies only to petroleum hydrocarbon (PHC) fractions F1 to F4; and
  - Groundwater guidelines can be excluded below 3.0 m for any substance.
- *Salt Contamination Assessment and Remediation Guidelines* (SCARG) (AENV 2001):
  - Applies to all land uses and governs by lithology;
  - The ecological direct contact pathway has separate guidelines derived specifically for surface soil (defined as the A-horizon) and subsoil (defined as the B- and C-horizons and the upper portion of the parent material); and
  - Applicable only to Electrical Conductivity (EC) and the Sodium Absorption Ratio (SAR).
- Contaminated Sites Management: Subsoil Salinity Tool (SST) (ESRD 2014a):
  - Applies to all land uses and governs by depth;
  - The rooting zone of the ecological direct contact pathway exists to a depth of 1.5 meters;
  - Applicable only to chloride at depth greater than 1.5 m; and
  - Used to predict upward migration of chloride into root zone (*i.e.,* 1.0 to 1.5 m) and calculates a predicted EC value within root zone and compares to SCARG.
- *Subsoil Petroleum Hydrocarbon Guidelines for Remote Forested Sites in the Green Area* (ESRD 2014b):
  - Applies only to the Green Area and governed by both lithology and depth;
  - The ecological direct contact pathway may be eliminated at a depth of 1.5 m in fine-grained material and may be eliminated at a depth of 3.0 m in coarse grained material; and

- Applicable only to PHC F1 to F4.

Given the above-mentioned guidelines and tools, there is some variability on whether the direct contact pathway is applicable at intermediate depths (between 1.5 and 3.0 m) for different chemicals of potential concern (COPCs). Additionally, while the pathway need not be applied to soils deeper than 3.0 m, owing to a lack of receptor presence, elimination of the ecological direct contact pathway is only applicable at such depths if another, more suitable guideline (such as a management limit), exists. Therefore, while various jurisdictions are aligned in the direct contact pathway being inoperative at depths greater than 3.0 m, for the vast majority of COPCs (with the exception of PHC F1 to F4) the direct soil contact guideline remains the governing remedial criteria.

2.0 OBJECTIVES

Millennium EMS Solutions Ltd. (MEMS) in association with InnoTech Alberta (InnoTech) looked to assess the applicability of the Ecological Direct Soil Contact pathway as it relates to agronomic receptor species for the White Area of the province of Alberta. Specifically, our research looks to establish a clear path toward the development of a scientifically defensible depth at which the ecological direct soil contact pathway is applicable.

3.0 METHODOLOGY

The design of the study was broken into five parts:

1. Describe what agricultural land-use in Alberta entails;
2. Establish which crop species are grown in the Province;
3. Based on the identified crop species, define their respective rooting depths;
4. Compare and evaluate the suitability of applying the ecological direct contact depth to 3.0 m in agriculturally zoned areas of the Province; and
5. Evaluate the applicability of the proposed ecological direct soil contact pathway exclusion depth using a well documented COPC (salt).

4.0 RECEPTOR IDENTIFICATION

4.1 Land Use

Agriculturally zoned land in Alberta (known as the White Area), accounts for 42% of the land, is primarily private, “settled”, land (approximately 75%) including 1.7 million individual title holders, of which approximately 50,000 own, or use most of the land for agricultural purposes. The White Area consists of the central, southern and the Peace River areas of the province and the main land uses include settlements, agriculture, oil and gas development, tourism and recreation, conservation of natural spaces, and fish and wildlife habitat (Alberta Government 2008). In 2016, farmed land accounted for 50,250,183 acres in Alberta and $6.6 billion of Alberta's real gross domestic product (AAF 2017).

The primary activities associated with agricultural land use include the ability to grow crops and raise livestock (CCME 2006). The development of soil quality guidelines for agricultural land use therefore must protect all receptors that are determined to be critical to the establishment and sustainability of crop growth and livestock production against adverse effects, irrespective of the variability associated with the agricultural practices. To achieve this level of ecological protection the endpoint values for COPCs were derived using laboratory and field toxicology data to predict adverse effects of chemicals on key ecological receptors including plants and soil invertebrates (as surrogates for ecological function of soil) as well as livestock and wildlife (CCME 2006).

4.2 Agronomic Species Distribution Databases

Agronomic data collected during the 2001, 2006, 2011 and 2016 Canadian Census was available for review by MEMS. The Agriculture Census is completed every five years for the purposes of providing comprehensive information on agricultural trends and farm variables within the agricultural sector across Canada. Using this census data the Alberta Ministry of Agriculture and Forestry released several publications detailing the 2001, 2006, and 2011 agronomic census data specific to lower levels of Alberta's geography, including counties, municipalities and improvement districts. The 2001 and 2006 data was subsequently divided into the five agricultural administrative regions (*i.e.,* South, Central, North East, North West and Peace), formerly identified by Alberta Agriculture and Rural Development. The 2011 data was subsequently divided into seven land-use regions (*i.e.,* Lower Peace, Lower Athabasca, Upper Peace, Upper Athabasca, North Saskatchewan, Red Deer and South Saskatchewan). This data, originally from Statistics Canada Census of Agriculture, was used to identify the most abundantly grown crop species (based on total acres) and their distribution throughout Alberta.

Supplemental agronomic census data for 2011 and 2016 were also retrieved directly from the Statistics Canada website, specifically Table: 32-10-0416-01 (Statistics Canada 2016). The data could be searched by hay and field crops specific for Alberta's geography including Census Agricultural Regions and Divisions. This data was less detailed in comparison to the Alberta Ministry of Agriculture and Forestry's publications (*e.g.,* fewer crop species) but provided data in a manner that allowed for the entire province to be efficiently analyzed for agronomic species distribution.

4.3 Crop Distribution in Alberta

To refine the census data, regional county information was filtered down according to Ecoregion overlap. In total, there were 70 counties across 11 Ecoregions available for review. The aerial extent of each Ecoregion was then used to determine the number of counties required to effectively represent the crop species within each Ecoregion. For example, Dry Mixed Grass Ecoregion was represented by two counties. The distribution for the number of counties per Ecoregion was based on Ecoregion area (km^2). Ecoregions 0 to 25,000 km^2 were represented by one county; 25,001 to 50,000 km^2 by two counties; 50,001 to 75,000 km^2 by three countries; 75,001 to 100,000 km^2 by four counties and >100,000 km^2 by five counties. The Montane and Alpine Ecoregions were excluded in the assessment as no agricultural census data was available for review. In total, 21 counties were selected to represent 11 Ecoregions.

For each county included in the assessment, the total percentage of each grown crop species was calculated by dividing the acres of grown crop species by the total area of defined agricultural land in the county for each census year. County data was then pooled to determine the most prevalent crop species for each Ecoregion per census year. Crop species that accounted for less than approximately 1% of the total agricultural land in the Ecoregion, even when summed together, were excluded from further evaluation. These crops included the following: corn, potatoes, buckwheat, soybean, sunflower, saffleflower, lentils, white bean, dry bean, sugar beet, ginseng, caraway seed, apples, strawberries, raspberries, blueberries, cranberries, grapes, sweet corn, tomatoes, cucumber, wax bean, cabbage, brussel sprouts, green onion, celery, spinach, peppers, and asparagus. For each census year, Ecoregions were compared to determine which crop species presented the greatest level of agricultural land use.

Based on a review of crop data for all Alberta Ecoregions over the past 16 years it is evident that just nine crop species account for approximately 98% of agricultural land use in the province (Figures 1, 2 and 3). These nine crop species include: alfalfa, barley, canola, durum wheat, hay/fodder, mixed grain, oats, peas and spring wheat.

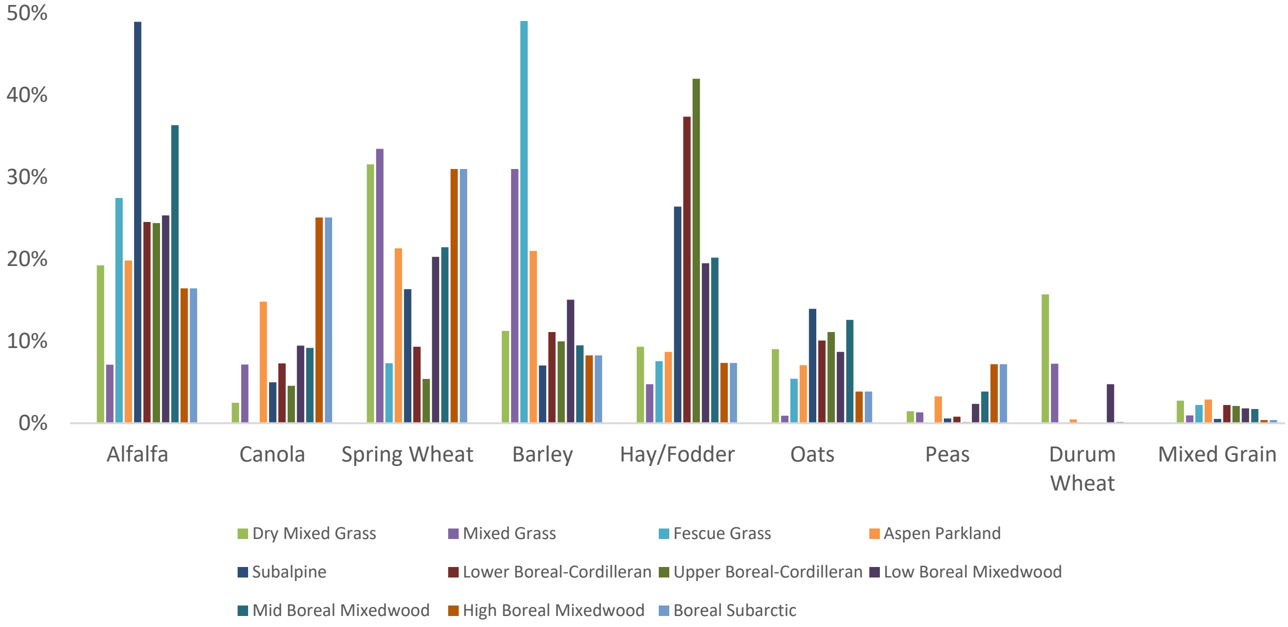

Figure 1. Percentage of total agricultural land used per crop species across Alberta Ecoregions in 2001 (2001 Census Data).

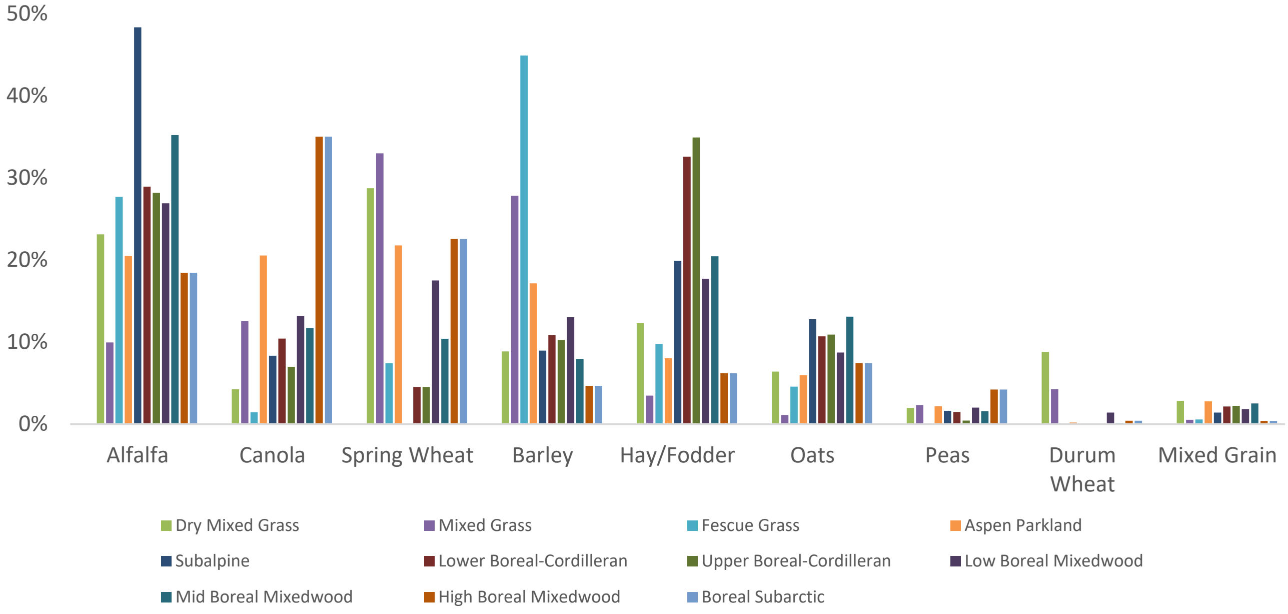

Figure 2. Percentage of total agricultural land used per crop species across Alberta Ecoregions in 2006 (2006 Census Data).

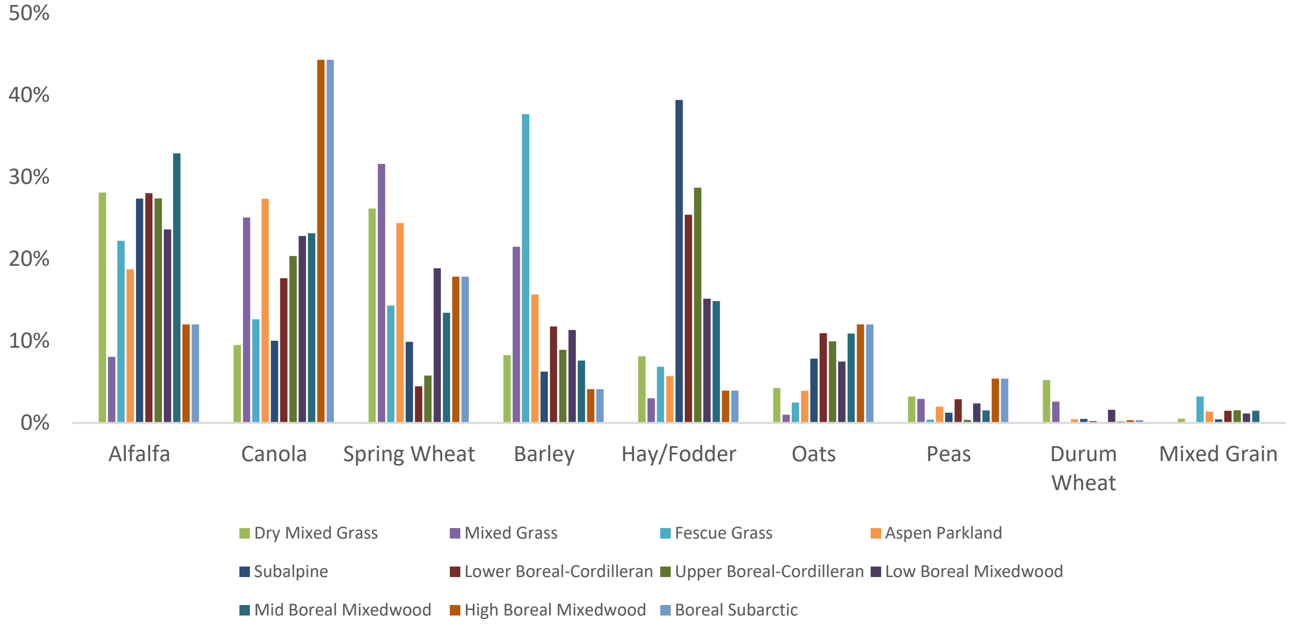

Figure 3. Percentage of total agricultural land used per crop species across Alberta Ecoregions in 2011 (2011 Census Data).

Data for 29 hay and field agronomic crop species were identified and their distribution was assessed across the province for each census year. Acres of grown crop species was available for 72 counties, among 19 census divisions (Appendix A). For each county, the total percentage of each grown crop species was calculated by dividing the acres of grown crop species by the total area of defined agricultural land in the county for each census year.

Based on a review of crop data for all Alberta census divisions for 2011, the same nine crop species were found to contribute to the agricultural landscape in each division (Figure 4). Interestingly, in 2016 lentils also accounted for a small percentage of the agricultural land use (accounting for slightly more than 1% of the overall total). Again, we find that ten crop species (the original nine plus lentils) made up more than 98% of agricultural land use in 2016 (Figure 5). Lentils are becoming an important crop species in Canada, not only for their economic value but for their nutrient cycling capabilities as well. Lentils have been found to provide rotational crop benefits as they are nitrogen-fixers providing added nutrients back to the soil system resulting in increased yields and quality of the following years selected crop (Alberta Pulse Growers 2018). The motivation may also exist financially as Canada has become one for the world’s largest producer/exporter of lentils largely due to the increased price for lentils which soared to a record high in 2016 of $1,000 a metric ton, more than double the 20-year average for lentils (ATB Financial 2017). This increase in price for lentils, crop rotation benefits, as well as the demand for lentils from countries such as India have likely increased the percentage of lentils crops grown in Alberta for 2016.

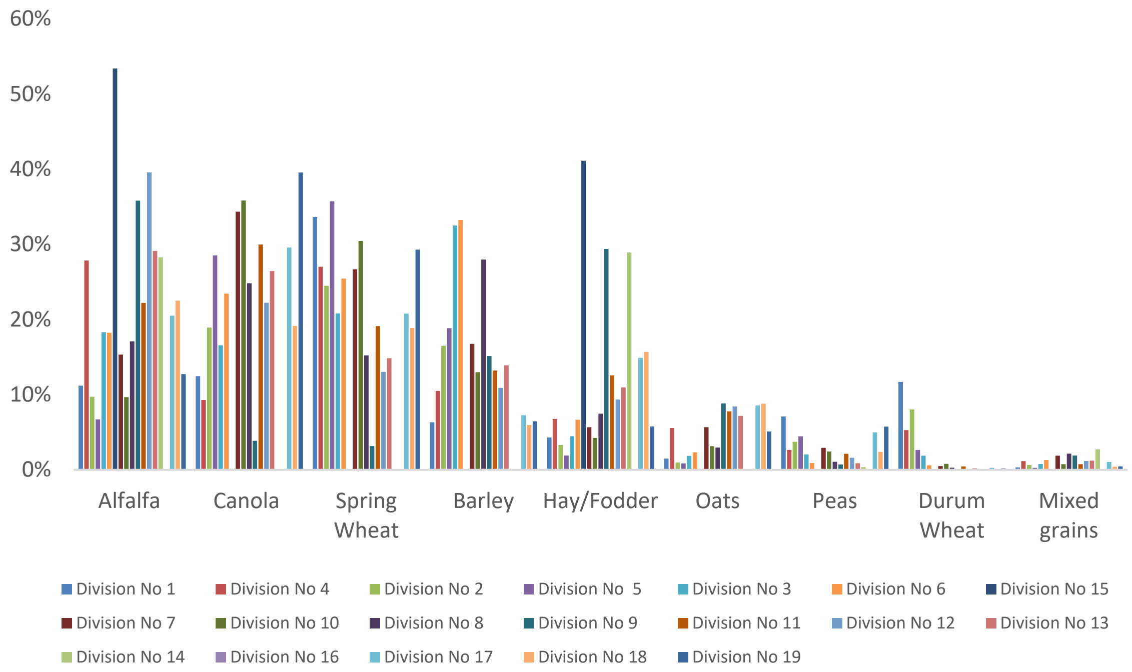

Figure 4. Percentage of total agricultural land used per crop species across Alberta census divisions in 2011 (2011 Census Data).

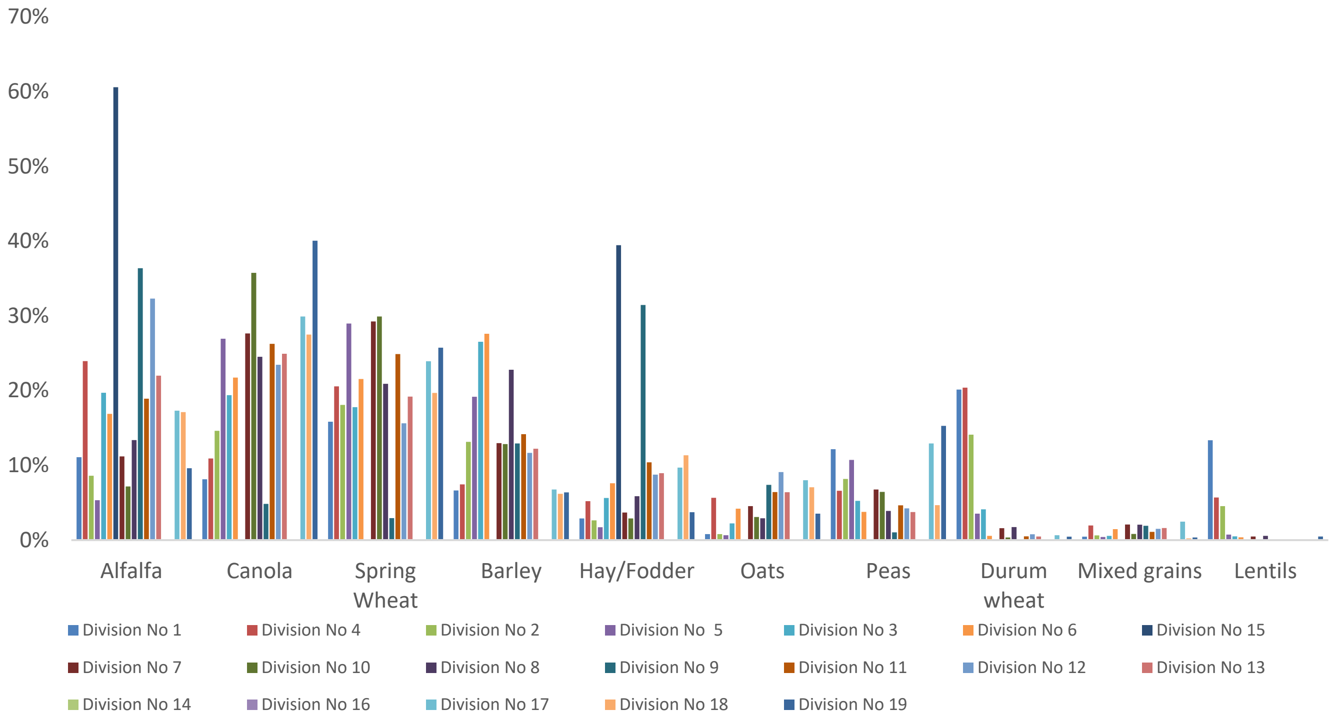

Figure 5. Percentage of total agricultural land used per crop species across Alberta census divisions in 2016 (2016 Census Data).

Based on this review there are 10 agronomic species which contribute to a clear majority of crop growth year over year in Alberta. This finding is substantiated in our analysis of the Alberta Ministry of Agriculture and Forestry publications which provided detailed agronomic census data in Alberta from 2001 to 2011. Here again, the data reveals that overall these same nine crop species make up a clear majority of agricultural land use (between 96 and 98%) (note that lentils were not documented as a contributing crop as the data ends in 2011 and lentils were not identified as a priority species until the 2016 census).

The remaining 2 to 4 % of the crops grown in Alberta consist of specialty crops such as corn, field bean, flax, potato, rye, winter wheat, triticale, combined fruit/berries/nuts and vegetables. According to agronomy and crop physiology researcher Dr. Jan Slaski, the crops most likely to enter into commercial production in higher acreages include hemp, flax, quinoa and Faba bean (Slaski 2018). An assessment of their rooting depths and salinity sensitivity is provided in Sections 5.3.1 and 6.2, respectively. The top nine-crop species are alfalfa, canola, spring wheat, barely, hay/fodder, peas, durum wheat, and mixed grain. Additionally, the data from Statistics Canada's website supported those findings for 2011 and 2016, with the addition of lentils. Overall, this review of census data (pooled from the same source but categorized by eco-region, division and county) indicates that these nine-crop species provide a strong basis for understanding receptor characteristics as it pertains to agronomic species grown in the White Area of Alberta.

5.0 ECO-CONTACT AND EFFECTIVE ROOTING DEPTH

5.1 Defining the Ecological Direct Soil Contact Pathway

A healthy ecosystem is dependent on a variety of soil processes, such as decomposition, respiration and organic nutrient cycling which are related to the involvement of invertebrate species and the availability of three distinct energy channels including; fungi, bacteria, and plant roots (Moore *et al*. 1988). The interrelation between these energy channels is important in microbial population dynamics as carbon availability is often a limiting factor to microbial growth in soil; carbon limitation is alleviated in the rhizosphere, but there is a limited region of the soil that is directly influenced by soil secretions (Dennis *et al*. 2010). The nutrient and energy cycling pathway is therefore intimately related to both invertebrate populations and the presence or absence of plant roots.

For the purposes of this Ecological Direct Soil Contact and Nutrient and Energy Cycling assessment, it is conservatively assumed that microbial and invertebrate activity, which influences the overall ecological health, exists within the rhizosphere to the maximum depth dictated by plant rooting activity, otherwise known as the biologically active zone. Delineation of the biologically active zone at a contaminated site is a prerequisite for describing exposure for ecological resources, potential transport mechanisms and quantifying associated risk (Sample *et al*. 2014). Because contaminants in soil below the depth of the biologically active zone are not accessible to biota, they do not represent a complete ecological exposure pathway and thus do not pose a threat to terrestrial plants or animals.

Researchers in Washington State, completed a study to define the biologically active zone based on ecological resources present at an upland site in southern Washington for the purposes of developing a point of compliance for remedial action (Sample *et al*. 2014). Their study found that the biologically active soil zone, which evaluated maximum observed depths for invertebrates, burrowing mammals and various shrub, forb and grass species did not exceed the maximum rooting depth for the deepest rooted plant. The study concluded that the maximum expected rooting depth could be proposed as the depth in soil below which it may be reasonably expected that contaminants do not pose a threat to terrestrial plants or animals, or otherwise would not be transported to locations that create exposure pathways (*i.e., via* burrowing species) (Sample *et al*. 2014).

A summary of literature related to soil invertebrates, particularly associated with depth is available in Startsev and Battigelli (2010) which highlights that soil fauna (invertebrates) play a variety of functional roles in soil processes, are influenced by soil chemical and physical properties, soil and rooting depth and management practices (*i.e.,* vegetation), thus suggesting that these organisms may be used as a biological indicator of soil health. Research has shown that microbes and invertebrates are highly correlated with plant roots (Canadell *et al*. 1996; Silva *et al*. 1989; Sample *et al*. 2015; Potapov *et al*. 2017; Fierer *et al*. 2003; Jobbagy & Jackson 2000; Startsev & Battigelli 2010). In general, microbial and invertebrate biomass decrease with depth; though their total abundance is lower in subsoil horizons, microorganisms remain quite numerous and active below 1 m (Blume *et al*. 2002) which creates a food source for soil invertebrates living deeper in the soil profile (Potapov *et al*. 2017). Microbial activity in the subsoil is strongly associated with the inputs of labile organic carbon provided by plant roots (Bernal *et al*. 2016; Fontain *et al*. 2007); therefore, the vertical distribution of both soil microbes and invertebrates is expected to be related to the distribution of plant roots. A field study completed by Potapov *et al*. (2017) demonstrated a strong correlation between soil invertebrates and the abundance of basal food sources suggesting soil fauna are involved in the deep soil carbon cycling *via* grazing on root-associated microorganisms, which in turn are correlated with rooting depths.

Studying soil fauna is considered challenging due to 1) the mechanism required for identification is soil extraction, which can be challenging to do effectively with depth, 2) the diversity and density of organisms in a given volume of soil, and 3) heterogeneity, particularly with depth. However, although the results are variable depending on the soil and climatic conditions, research has shown that the majority of soil organisms are found in the upper soil horizons (Startsev & Battigelli 2010), largely within the surface 10 cm (NRCS 2013) in temperate, semi-arid regions such as those found in southern Alberta. Decreasing density with depth is the general pattern associated with soil fauna, however the vertical distribution can be influenced by a number of factors such as soil temperature (seasonal influence), soil moisture, vegetation, soil type (physical and chemical), microhabitat (pore space), humidity; all of which influence the ability to accurately assess soil invertebrate distribution. In general, research suggests that although soil fauna can extend to a depth equal to the root penetration in soil, the likelihood of presence at deeper soil depths below the rooting zone is limited due to the lack of pore space and food availability (Startsev & Battigelli 2010).

Startsev & Battigelli (2010) assessed soil mesofauna densities with depth at 6 well sites in southern Alberta under either alfalfa or canola crops. Their research found the vertical distribution of soil fauna was variable across individual sites and between sites, however at the majority of the sites, 73% or more of the fauna were found in the upper soil horizon. Although specimens were collected at depths equivalent to, or slightly greater than, the maximum observed rooting depths, it was identified that the sampling method employed in the study had limitations. However, the study did demonstrate, given the lack of invertebrate specimens beyond the rooting depth, that limited exposure risk and/or contribution to ecological health would be expected.

5.2 Jurisdictional Review of Public Policy

The jurisdictional guidelines for soil remediation depths for the ecological soil direct contact pathway vary between provinces and territories. There is also a federal guideline developed by the CCME for the Canada-wide standards for petroleum hydrocarbons (PHC CWS) in soil that discusses the soil remediation depths for the ecological soil direct contact pathway. The Five-Year Review of the PHC CWS: Ecological, Direct Soil Contact Guidance discusses eliminating the soil contact pathway below 3 metres (Ecological Criteria Advisory Sub Group 2006). The CCME PHC CWS contamination guideline has been implemented in Alberta, Saskatchewan, Manitoba, Northwest Territories, Nunavut and Ontario (CCME 2014). Yukon has not adopted the guideline yet but plans to with the amendment of their Environment Act. The Atlantic Provinces follow the Atlantic Risk Based Corrective Action (RBCA) guidelines; the RBCA is considered an equivalent approach to the CCME PHC CWS contamination guideline (CCME 2014). British Columbia and Québec have not signed the accord for the adoption of the CCME PHC guideline, but British Columbia is considering adopting the guideline and Québec still participates in the science reviews (CCME 2014). The provinces and territories also have their own guidelines that are outlined below (Table 1). Expanding beyond Alberta, it would appear that there is no clear direction provided, other than on a site-specific basis, for the operative depth of the ecological direct contact pathway.

Table 1: Jurisdictional Review of Soil Remediation Guidelines for the Ecological Soil Direct Contact Pathway.

Province/Territory	Guideline(s)
Alberta	*Alberta Tier 1 Soil and Groundwater Remediation Guidelines* outline the methodology for modification of the ecological direct contact pathway for BTEX and PHC F1 to F4 (AEP 2016a): • Below 1.5 m and above 3.0 m within 5 m of a wellhead the subsoil eco-contact guidelines may be applied (BTEX and PHC F1 to F4); and • Below 3 m at any site (PHC F1 to F4). *Subsoil Petroleum Hydrocarbon Guidelines for Remote Forested Sites in the Green Area* outlines the methodology for excluding the ecological direct contact pathway of PHC F1 to F4 (ERSD 2014b): Below 3 m at remote forested sites in the Green Area for coarse-grained soils and below 1.5 m at remote forest sites in the Green Area for fine-grained soils.

Table 1: Jurisdictional Review of Soil Remediation Guidelines for the Ecological Soil Direct Contact Pathway.

Province/Territory	Guideline(s)
British Columbia	*British Columbia Environmental Management Act Contaminated Site Regulations* (CRS) Part 5, Section 11 (1) (c.3) (BC Government 2018): • 15 m from well head at depths ≥ 3 m, industrial land use standards apply (all land uses), and • < 15 m from well head at depth ≥ 2m and < 3 m, commercial standards apply (for wildland land use) and at depth ≥ 3 m industrial standards apply. Protocol 13 Screening Level Risk Assessment uses a surface 1 m approach to characterizing plant and animal exposure to contaminants in soil (excludes deep rooting vegetation) (BC MECCS, 2017).
Saskatchewan	*Saskatchewan Environmental Code* (Government of Saskatchewan 2016) outlines eliminating the Ecological Soil Contact pathway if: • Substance of potential concern (SOPCs) are PHCs or BTEX compounds at the site and SOPCs are more than 3 meters below grade or SOPCs are between 1.5 and 3 meters below grade and engineering controls and administrative controls are present; • the site is paved or capped or no productive use of the soil system is anticipated; • it is demonstrated that ecological exposure or receptors are controlled or not present; • PHC's and BTEX in less than 1.5 meters are always considered to be accessible for direct contact; and • landscaped areas exist (or are planned) the pathway should remain active.
Manitoba	Manitoba's Contaminated/Impacted Sites Program adopts the CCME guidelines (MSD 2016).
Ontario	Ontario's *Rationale for the Development of Soil and Ground Water Standards* for use at Contaminated Sites in Ontario references to the CCME's ecological direct soil contact values and ecological protection numbers as suitable levels of protection (Ontario Ministry of Environment, 2011).
Québec	No sources found in English with reference to eco-contact pathways or remediation standards.
New Brunswick	Atlantic Risk Based Corrective Action (RBCA) *Ecological Screening Protocol Scientific Rationale* references the CCME regarding protection of plants and soil invertebrates – particularly for soil screening levels (Atlantic PIRI, 2013).

Table 1: Jurisdictional Review of Soil Remediation Guidelines for the Ecological Soil Direct Contact Pathway.

Province/Territory	Guideline(s)
Nova Scotia	See Atlantic RBCA notes.
PEI	See Atlantic RBCA notes.
Newfoundland	See Atlantic RBCA notes.
Yukon	Yukon's *Environment Act* references a numerical restoration standard depth of 3 m (Yukon Regulations, 2014).
NWT	Implemented CCME PHC contamination guideline (CCME, 2014).
Nunavut	*Environmental Guideline for the Management of Contaminated Sites* document refers to ecological receptors/direct soil contact but does not provide any detailed information (Government of Nunavut, 2014).
Federal	CCME – direct soil contact exposure pathways for ecological receptors in subsoil (>1.5 m) (CCME, 2014).

5.3 Root Zone and Soil Depth

According to the CCME, most direct soil exposure to human and ecological receptors occur at or near soil surface; therefore, surface soils are routinely defined as those within the upper 1.5 m of the soil profile. Soils located at deeper depths are less accessible to humans and typically less sensitive to adverse effects limiting the ecological function of the ecosystem. The problem with defining subsoil guidelines that are based on the exclusion of a pathway at depths greater than 1.5 m is that it does not account for the potential for soil disturbances that can result in the relocation of subsurface soils to near surface conditions (CCME 2006).

In Alberta, soil and subsoil is generally defined according to a 3 m cut off depth, whereby a subsoil unit is considered applicable at depth greater than or equal to 3 m for most COPC. The exceptions to this generic definition include:

- Directive 079 (*Surface Development in Proximity to Abandoned Wells*): Subsoil is defined at depths below 1.5 m bgs within 5 m of a wellhead (AER 2014);
- *Subsoil Petroleum Hydrocarbon Guidelines for Remote Forested Sites in the Green Area*: Subsoil is defined at depths below 1.5 m bgs for fine-grained soil and at depths below 3 m bgs for coarse-grained soils (ESRD 2014b); and
- *Salt Contamination Assessment & Remediation Guidelines*: Topsoil is defined as the L, F, H, O and A horizons (SCWG, 1998) or equivalent surficial material where these horizons are absent, and

> Subsoil is defined as the B and C horizons and the upper portion of the parent material (AEP 2016a and AENV 2001).

Defining the soil units as Topsoil, Soil or Subsoil is not by their definition a means for the inclusion or exclusion of the Eco-Contact pathway. Exclusion of the Eco-Contact pathway is only available under specific circumstances. For example, within the framework outlined in the *Subsoil Petroleum Hydrocarbon Guidelines for Remote Forested Sites in the Green Area*, the Eco-Contact pathway is not considered active within the Subsoil; however, this only applies to PHC fractions F1 to F4 (ERSD 2014b). Otherwise, exclusion of the Eco-Contact pathway would require implementation of exposure control, which is not available under the *Alberta Tier 2 guidelines* (AEP 2016b).

For other COPCs, such as metals, that do not have alternative remedial endpoint values for pathways other than the Eco-Contact pathway, the remedial objectives for the Eco-Contact pathway function as management limits (AEP 2016a). Therefore, in the absence of an alternative remedial endpoint, the subsoil Eco-Contact pathway can be applied at depths exceeding the rooting zone, regardless of whether the ecological receptors are present.

Salinity on the other hand is approached using the *Salt Contamination Assessment & Remediation Guidelines* (SCARG) (AENV 2001 and AEP 2016a). This guideline was developed for the root zone (*i.e.,* surface to 1.5 m bgs) and uses the concept of equivalent land capability in deriving remedial objectives for Topsoil and Subsoil. As outlined above, the definition for the Topsoil and Subsoil units in SCARG are considerably different than other COPCs (AENV 2001). Under this framework the remedial objectives for EC and SAR within the root zone are not based on the sensitivity of the receptor to the COPC but rather the value of the salinity parameter relative to non-contaminated background conditions (AEP 2016a).

Under a Tier 2 approach, salinity in the subsoil is assessed using the SST, which derives chloride guidelines in the subsoil to protect the various receptors present on and off a site. The SST assumes the deeper portion of the root zone (*i.e.,* 1.0 to 1.5 m bgs) is a receptor of concern; however, development of a Tier 2 guideline for salts within the root zone depth interval of 0 to 1.5 m bgs is beyond the scope of the SST. Therefore, the root zone receptor (*i.e.,* the Eco-Contact pathway) is still assessed using SCARG (ERSD 2014a).

5.4 Rooting Depth of Agronomic Species Present in Alberta

A literature review was conducted to assess the maximum rooting depth of various crop species relevant to Alberta as per the findings of the agronomic species distribution assessment (Section 3.0). Relevant agronomic species were selected through a review of the Alberta Crop Census data for the years 2001, 2006 and 2011. As the agricultural census data is specific to the county, municipality and improvement district level, which are equivalent to Census Consolidated Subdivisions (AARD 2014).

Therefore, for any site located on Agricultural land in Alberta, the census data can be used to identify the crop species grown and calculate the percent of total agricultural land covered by each crop species.

There are several methods by which the rooting depth of plants can be defined. Specifically, these include:

- Effective Rooting Depth – the zone, or depth, by which most of the plant available water is obtained.
- 95% Root Distribution – the depth at which 95% of the root biomass is accounted for.
- Maximum Root Depth – the maximum rooting depth, under ideal conditions, that the deepest root would be expected to reach.

A summary of typical rooting depths for the major crop species identified across Alberta is presented in Table 2.

Table 2: Summary of Crop Rooting Depths (m) and Root Distribution in Soil Profile

Crop	Effective Rooting Depth						95 % Root Distribution	Maximum Root Depth
	USDA[1]					AAF[2]	Fan *et al.* (2016) & Canadell *et al.* (1996)	
	Range	Low	High	Average	±			
Alfalfa	1.0–2.0	1.0	2.0	1.50	0.5	1.2	1.356	3.7
Barley	1.0–1.5	1.0	1.5	1.25	0.3	1	0.996	1.7
Canola	1.0–1.5	1.0	1.5	1.25	0.3	1	0.902	1.6
Durum Wheat	-	-	-	-	-	-	-	2.2
Hay/Fodder	0.6–1.0	0.6	1.0	0.80	0.2	0.5	-	-
Green Peas	0.6–1.0	0.6	1.0	0.80	0.2	0.7	0.85	1.6
Lentils	0.5–1.0	0.5	1.0	0.75	0.3	-	0.737	1
Corn (grain, silage)	1.0–1.7	1.0	1.7	1.35	0.4	1	0.889	2.4
Spring Wheat	1.0–1.5	1.0	1.5	1.25	0.3	1	1.038	3

[1]United States Department of Agriculture (2016); [2]Alberta Agriculture and Forestry (2016).

In general, there is limited research completed on novel crop species with respect to the roots. Among crops that have the potential for larger commercial production, hemp appears to have the highest rooting potential. Researchers in Italy found hemp roots at a depth of 100 to 130 cm under various growing conditions and to a maximum depth of 200 cm under moisture limited growing conditions (Amaducci *et al*. 2008); however, soil conditions were vastly different than in Alberta. 10 to 12 percent of the flax currently grown in Canada is grown in Alberta, which is expected to increase as uses and benefits of flax are identified. The root mass of flax is among the lowest of all Prairie field crops and the proportion of flax roots below 60 cm (and especially 80 cm) depth is lower than other field crops (FCC 2018). Quinoa can be grown in various zones in Alberta as north as the Lower Peace (Falher) region and has roots reaching depths of approximately 1 m. Similarly, Faba bean is a novel crop being recommended for cold/wet zones and although there is limited information available on rooting depths, research suggests roots can reach depths of approximately 1 m (Slaski 2018).

5.5 Effective Rooting Depth

The effective rooting depth shown in Table 2 is based on the expected maximum rooting depths reached by annual crops near the time of peak water use assuming no expected root penetration restrictions (USDA 2016). These values represent the root depth when grown in deep, well drained, and adequately irrigated soils. The effective root zone depth (ERZ) which are the values provided by AAF (2016) are the depths at which most plant roots are concentrated, and plants extract the majority of their water from this zone. In actuality, most plants extract the majority of water in the upper root zone with decreasing extraction the deeper the roots extend into the soil (Figure 6).

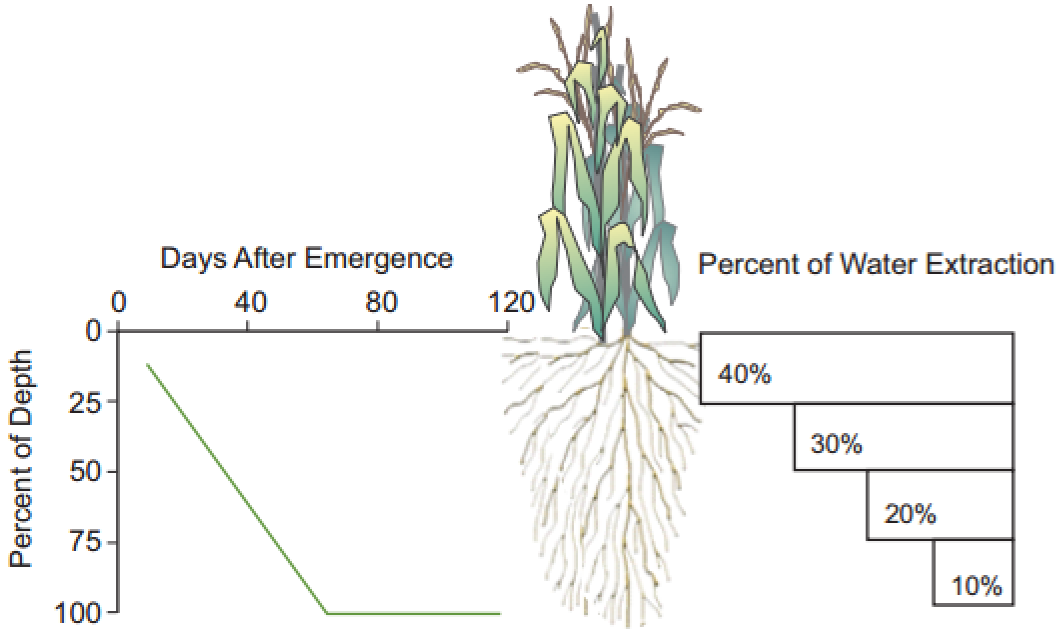

Figure 6. Effective root zone soil water extraction and plant root development patterns (taken from Alberta Agriculture and Forestry [2016]).

The pattern of ERZ water extraction and plant root development is supported by the root distribution work completed by Fan *et al*. (2016) and others. In their study, root mass is not proportionately distributed throughout the effective rooting depth. Instead, a linear decrease in root mass distribution is found at increasing depths for monocotyledons and a near exponential decrease in root mass is found with increasing depth for dicotyledons (Fan *et al*. 2016). Their research expanded on previous root distribution models in an effort to capture the effects of root biomass, root turnover, root distribution and maximum rooting depth. In their study, 96 root distribution profiles were compiled for a variety of temperate agricultural crops and fitted to a modified logistic dose response curve for 11 specific crop species. From this model they were able to predict the depth at which 95% of the root mass would be accounted (Table 2).

Overall, the research shows that a least half of all root biomass is found in the upper 20 cm of soil. Alfalfa, which showed the deepest rooting profile, had 95% of root mass present in the upper 136 cm of soil and a maximum rooting depth of 177 cm; it is considered to be the deepest rooting of the crops investigated. Hence, it is also a suitable surrogate candidate for assessing rooting depths for temperate agricultural crops. This is because most, if not all, temperate climate crops are expected to root to depths less than that of alfalfa. These results were corroborated through a research study completed in southern Alberta evaluating wheat, canola and alfalfa roots and invertebrates with depth (Startsev & Battigelli 2010). Although it wasn't the objective of the study, the data indicate that alfalfa is the deepest rooted of the three-species investigated, closely followed by canola. Canola roots were observed down to 150 cm, however the root volume at this depth was subject to measurement error being detected to the third decimal place. Wheat roots were not observed below 100 cm, with the vast majority within 50 cm of the soil surface.

A literature review of typical rooting depths for alfalfa supported maximum effective rooting depths in the 100 to 200 cm range. Locally, a study completed in southern Alberta evaluating rooting depths of alfalfa and canola on reclaimed wellsites indicated alfalfa roots seldom exceeded 150 cm and when present between 150 and 200 cm, they were present in very small quantities (Startsev & Battigelli 2010). The majority (>90%) of the root mass was located in the top 50 cm of soil. A single study with a maximum rooting depth of 360 cm was also identified. The source of this value is from a variety of crop rooting depth studies conducted by J. Weaver in 1926. The depths of the root structure were longest after year two extending to nearly 10 feet (3 meters) but makes no mention of the root biomass at such depths. In relation to crop production, alfalfa prefers a rooting habitat with deep, permeable soil (loam, silt loam, or sandy loam) and is very sensitive to poor aeration (Weaver 1926). Specifically, the crop does not perform well if water is within 50 to 100 cm of ground surface.

The association of the depth to contamination in relation to a plants ERZ and maximum rooting depth isn't well defined in literature. However, as the majority of water and nutrients are absorbed within the ERZ it can be assumed that any impacts occurring within a plants ERZ would have the highest likelihood for causing deleterious effect.

6.0 VALIDATION OF ECO-CONTACT METHODOLOGY (SALT SENSITIVITY)

The plant's ability to endure the effects of salt-affected soils is referred to as the salt sensitivity. Salt sensitivity varies from one species to another and can change during the growth cycle of a plant (Acosta-Motos *et al*. 2017; Hillel 2000).

Glycophytes are salt-sensitive plants and their growth is inhibited and/or prevented in high levels of salinity. In contrast, halophytes are salt-tolerant plants and can grow in the presence of high salinity. Anatomical and physiological differences between salt-sensitive glycophytes and salt-tolerant halophytes can explain the variability in salt sensitivity. Most crop species are considered to be glycophytes and are sensitive to salt-affected soils (Acosta-Motos *et al*. 2017; Hillel 2000). Glycophytes can have severe growth inhibition or be killed by 100-200 mmol L^{-1} of NaCl, while halophytes can survive 300 mmol L^{-1} of NaCl (Zhu 2007).

Soil salinity is known to vary considerably with time, location, soil type and depth. However, low salinity soils can suppress plant growth while high salinity soils can cause plant death (Peel 2004).

Sodium chloride (NaCl) constitutes the majority of salts present in anthropogenic impacted saline soils. Excess external Na^+ ions in soil can impair potassium uptake and lead to accumulation of Na^+ in plant cells which can lead to toxicity in most plants. Some plants are also affected by high concentrations of Cl^- ions (Bright & Addison 2002). Na^+ and Cl^- ions in excess cause osmotic stress and ionic toxicity in plants. Osmotic stress negatively impacts the plant by decreasing the plant's ability to absorb water and nutrients from the soil. Plants also have to utilize more energy during osmotic stress to extract the water and nutrients it needs from the soil. Water is essential for sustaining turgor pressure in plants (Chen & Jiang 2010; Zhu 2007). Turgor pressure in plants maintains overall plant structure and various physiological processes, such as photosynthesis (Holding & Streich 2013).

Some plants (mainly salt-tolerant halophytes) are able to adapt to and tolerate high salinity soil by osmotic adjustment. Osmotic adjustment allows the plant to continue to extract water from the saline soils by compartmentalizing the absorbed Na^+ and Cl^- ions into vacuoles, meanwhile synthesizing compatible non-toxic organic solutes to help protect the cell from stress. This mechanism helps maintaining water intake, turgor pressure, and avoiding ionic toxicity. Ionic toxicity will occur if ions are able to accumulate in the plant's tissues over time (Chen & Jiang 2010; Zhu 2007).

The Contaminated Sites Soil Task Group (CSST) bases the direct soil contact to plants on EC_{50} response and the toxicity data must be divided by either mortality, ecologically relevant response or non-lethal response (Bright & Addison 2002). The CCME protocol for deriving soil thresholds protective of soil invertebrates and plants differs from the CSST. CCME does not exclude data based on different toxicity endpoint used and determines a soil concentration that is based on the 25th percentile of the ranked concentration data (Bright & Addison 2002).

6.1 Indicators of Salt Stress

Salt stress is a condition in plants where high soil salinity causes a decrease in growth, changes in plant physiology, increased plant mortality and limits crop production. High soil salinity can occur naturally or from sources such as irrigation or previous land use (Munns 2002; Zhu 2007). Plants respond to salt stress in a variety of ways and can affect the life stages of plans differently.

One of the first signs of salt stress in many plants is the reduction or cessation of leaf surface growth (Rasool *et al*. 2013). Salt stress can cause other stresses in a plant including osmotic stress, ionic stress and oxidative stress. Processes necessary for plant growth and survival such as photosynthesis, protein synthesis and lipid metabolism are also affected by salt stress. Salt stress has also been shown to reduce the ability of a plant to take up water and to reduce shoot growth (Rasool *et al*. 2013).

Overall, salt stress reduces crop yield and quality in glycophytes but salt stress can be managed depending on the cause of soil salinity. Methods for reducing salt stress in crops include changing farm management practices, remediation of the high salinity soil and growing salt tolerant crop species (Munns 2002).

6.2 Crops Sensitivity Analysis

A crop sensitivity analysis was conducted using Food and Agriculture Organization (FAO) of the United Nations crop salt tolerance data (FAO – Irrigation and Drainage 2002). The data was reviewed and salt sensitivity for the most prevalent crops in Alberta was plotted as a function of relative reduction in plant yield *versus* increasing salinity in soil (Figure 7).

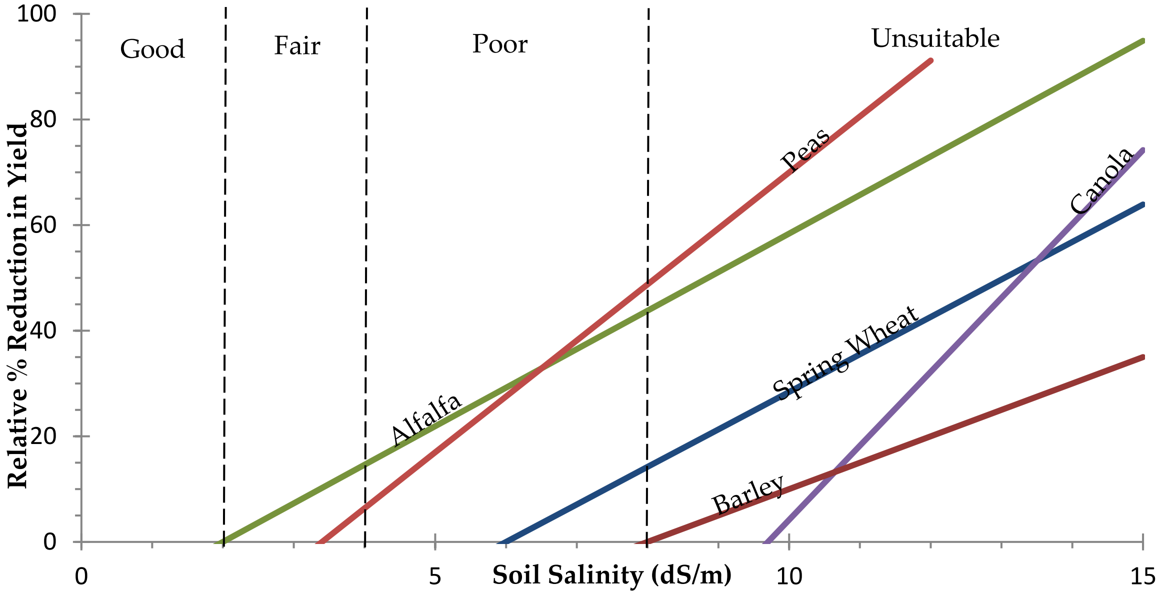

Figure 7. Crop sensitivity analysis for a select number of prevalent crop species in Alberta. The SCARG classification of soil suitability is represented by vertical dashed lines (AENV 2001).

As displayed in Figure 7, the following interpretations were formulated about the most prevalent crops in Alberta:

- Alfalfa's salt-sensitivity is classified as moderately-sensitive, with a threshold EC value of 2.0 ds/m and a 7.3% decrease in crop yield with each additional 1 ds/m increase in EC.
- Peas salt-sensitivity is classified as moderately-sensitive, with a threshold EC value of 3.4 ds/m and a 10.6% decrease in crop yield with each additional 1 ds/m increase in EC.
- Spring wheat salt-sensitivity is classified as moderately-tolerant, with a threshold EC value of 6.0 ds/m and a 7.1% decrease in crop yield with each additional 1 ds/m increase in EC.
- Barley salt-sensitivity is classified as tolerant, with a threshold EC value of 8.0 ds/m and a 5% decrease in crop yield with each additional 1 ds/m increase in EC.
- Canola salt-sensitivity is classified as tolerant, with a threshold EC value of 9.7 ds/m and a 14% decrease in crop yield with each additional 1 ds/m increase in EC.
- The divisions for identifying crop tolerance as defined by maintaining at least 80% crop yield, is as follows:
  - Sensitive = 3 ds/m or less;
  - Moderately Sensitive = between 3 and 6 ds/m;
  - Moderately Tolerant = between 6 and 9 ds/m;
  - Tolerant = between 9 and 15 ds/m; and

- Salinity levels in soils that are higher than 15 ds/m are generally considered unacceptable for most crops.

However, these analyses assume the entire root mass of the plant is in direct contact with salinity. In Canada, toxicity thresholds are developed utilizing the Environment Canada (Env. Can. 2007) Biological Test Method which is a test developed to measure emergence and growth of terrestrial plants exposed to contaminants in soil. The majority of ecological toxicity reference values which are defined as the exposure concentration or dose of COPC that is not expected to cause an unacceptable level of effect (AB Gov 2017), are developed utilizing this method. Challenges arise when utilizing this method for evaluating the risk associated with salinity with depth. It is largely unknown what the toxicity thresholds would be when the COPC is not within direct contact with the plant and is beneath the effective rooting zone. Measuring the ecological response of agricultural crops to salinity utilizing the Environment Canada Biological Test Method would not provide an accurate representation of the risk associated with elevated concentrations deeper within the soil profile. The influence of NaCl on ecological receptors, when present below the effective rooting zone, is currently unknown, as no information could be found in the peer reviewed literature or the grey literature that evaluated this effect. Roots have been shown to be extremely adaptive to local soil conditions (Drozdowski & Thacker 2018) and may exhibit a variety of mechanisms to adapt to a variety of conditions, including the presence of elevated NaCl with little to no adverse effects on plant health. Additional research is required to assess the effect of NaCl presence at depths below the effective rooting zone to confidently develop an ecological direct soil contact exclusion depth.

There are other crops that are grown in Alberta that are salt sensitive and shallow rooting but are not one of the top nine crop species commercially grown in Alberta. Given that these crops were not identified as priority species commercially grown in Alberta, they were not considered in this report for their distribution. Salt sensitivity data has been provided for carrots, dry beans, strawberries (USDA 2016), hemp (Levy & Underwood 2018), quinoa (Razzaghi *et al*. 2011), flax (Slaski, 2018) and Faba bean (Nader *et al*. 2005).

- Carrots salt-sensitivity is classified as sensitive, with a threshold EC value of 1.0 ds/m and a 14% decrease in crop yield with each additional 1 ds/m increase in EC.
- Dry beans salt-sensitivity is classified as sensitive, with a threshold EC value of 1.0 ds/m and a 19% decrease in crop yield with each additional 1 ds/m increase in EC.
- Strawberries salt-sensitivity is classified as sensitive, with a threshold EC value of 1.0 ds/m and a 33% decrease in crop yield with each additional 1 ds/m increase in EC.
- Hemp salt-sensitivity is considered variable due to the large number of varieties available, however as a whole the species is not considered tolerant of saline soils

- Quinoa salt-sensitivity would be considered tolerant, as it is classified as a facultative halophyte crop. There is limited documentation on the threshold soil EC that causes yield reduction, however one study showed a threshold EC value of 3-6 ds/m.
- Flax varieties have been developed which are considered moderately salt tolerant to tolerant.
- Faba beans salt sensitivity is classified as moderately tolerant with a threshold EC between 5.5 and 6 ds/m for the more salt tolerant varieties.

7.0 AGRONOMIC RECEPTOR EVALUATION FOR DIRECT SOIL CONTACT

Agricultural crop species are routinely used as ecological receptors for assessing the Eco-Contact pathway for contaminated soil (CCME 1999 and updates). Radishes and lettuce, for example, are used by the CCME as ecological receptors for contaminated soil when deriving endpoint values for barium, ethylbenzene, xylene and chromium. Other crop species that have been used by the CCME include alfalfa, barley and northern wheatgrass for methanol; legumes and grain stalk for barium; and tomatoes for chromium. For polycyclic aromatic hydrocarbons (PAH) limited information is available for terrestrial plants but the information that is available is specific to agronomic species (CCME 1999 and updates). Salinity parameters, including electrical conductivity (EC) and sodium adsorption ratio (SAR), however are not assessed in the same manner due to the presence of variability inherit in background soil quality. Thus, EC and SAR are assessed within the root zone on a site-specific basis using background soil quality as the control.

Under Alberta's *Environmental Protection and Enhancement Act* the governing principles for industrial activities and remediation objectives include, among others, the conservation of equivalent land capability (Province of Alberta 2000). Therefore, remedial objectives for EC and SAR within the root zone are not based on the sensitivity of the receptor to the COPC but rather the value of the salinity parameter relative to non-contaminated background conditions. These objectives are outlined in the *Alberta Tier 1 Soil and Groundwater Guidelines* (AEP 2016a) and *the Salt Contamination Assessment and Remediation Guidelines* (SCARG) for topsoil and subsoil (AENV 2001). Other guidelines are available for salinity impacted sites; however, their application is specific to the management of drilling waste material (*i.e.*, Directive 50, AER 2016).

Hence, there exists precedence for the use of an agronomic species in the establishment of a unified ecological direct soil contact exclusion depth. A suitable surrogate would be one that is found throughout the province, is considered deep rooting, and is salt-sensitive (*i.e.*, alfalfa).

8.0 DATA GAPS AND AREAS OF POTENTIAL ADVANCEMENT

The main knowledge gaps identified through this review and suggestions for further work are identified in Table 3. Ultimately, to develop a unified ecological direct soil contact exclusion depth, these gaps would need to be addressed.

Table 3: Knowledge gaps identified and suggestions for further work

Gap #	Knowledge Gap	Suggestions for Further Work
1	Observational evidence sourced from Alberta to support the assumption that microbial and invertebrate activity, which influences the overall ecological health, exists within the rhizosphere to the maximum depth dictated by plant rooting activity, otherwise known as the biologically active zone.	• A field study is recommended to assess the correlation between abundance and vertical distribution of soil invertebrates as related to soil organic matter, microbial biomass and plant roots. • The objective of this study would be to define the biologically active zone to identify the depth in soil beyond which contaminants would not be a source of exposure or risk to plants and animals (including soil fauna).
2	Validation of maximum and effective rooting depths for alfalfa under various soil conditions in agricultural regions in Alberta	A field study is recommended to acquire observational evidence to support the literature findings in this project and develop the weight of evidence for the use of alfalfa as a surrogate species.
3	Eco-toxicity evaluation of the impact of multiple concentrations of NaCl at various depths within and below the effective rooting zone for a suitable surrogate species in Alberta (*i.e.*, alfalfa) to evaluate the effect salinity has on root structure and distribution within the soil profile.	A lab/greenhouse study is recommended to assess the effect NaCl has on plant health (both above and below ground) when found at various depths within the soil profile.

9.0 FIELD STUDY SCOPING

The overall objective of further research in this area is to establish the weight of evidence for the establishment of a unified ecological direct soil contact exclusion depth. Based on this review two (2) studies are recommended to address the knowledge gaps identified for establishment of an ecological direct soil contact exclusion depth for salinity (NaCl) for agricultural regions in Alberta. A brief description of the recommended studies is provided below.

9.1 Field Study

A field study is recommended to validate the depth of the biologically active zone for agricultural regions of Alberta and establish whether the maximum expected rooting depth of a surrogate agronomic species (*i.e.*, alfalfa) could be proposed as the depth in soil below which it may be reasonably expected that salinity would not be a source of exposure or risk to terrestrial plants or animals (including soil fauna). Specific project objectives required include:

1) Validate effective and maximum rooting depth for alfalfa grown under Alberta soil and climatic conditions; and
2) Assess the correlation between abundance and vertical distribution of soil invertebrates as related to soil organic matter, microbial biomass and plant roots to validate the depth of the biologically active zone.

Experimental design for a study of this nature is challenging given 1) the extent of the agricultural regions in Alberta, 2) difficulties associated with studying the ecology of deep dwelling soil invertebrates, and 3) the uncertainty associated with defining maximum rooting depth given the fine nature of deep roots (*i.e.,* <2 mm) and difficulty with quantification.

The scope of the study would be limited to site evaluations with alfalfa crops grown in agricultural regions of Alberta. Alfalfa has been identified as the deepest rooting species commercially grown in agriculture regions of Alberta, is considered sensitive to salinity and is ubiquitous across all ecoregions in the province; therefore it is expected to serve as a conservative surrogate for all other agronomic species grown.

With no budget constraints we would develop an experimental plan that would allow us the ability to assess the variability within an ecoregion, as well as the ability to compare variability among ecoregions. However, given the agricultural regions of Alberta encompass 11 ecoregions, even with the scope of the project confined to one plant species, this would result in unrealistic project expectations.

To develop an experimental plan that is both logistically feasible and fiscally reasonable the trade-offs between assessing the variability within an ecoregion *versus* generalizing for all agricultural regions of Alberta must be considered.

Although the agricultural region of Alberta is comprised of 11 ecoregions, the variability associated with rooting characteristics for agricultural species is likely more influenced by soil type and climate than ecoregion boundaries. Therefore, to determine the relative location and minimum number of samples required to be representative of the agricultural region of the province the ecoregions map of Alberta was overlain on the soil groups map of Alberta. This map along with the following considerations were used to select the recommended number of sampling locations:

1) The areal extent of the ecoregion in comparison to the overall agricultural area of the province;

2) The representativeness of the ecoregion considering other factors such as soil zone, and climate.

It is proposed to establish a minimum of four (4) independent sampling locations; one within each of the brown, dark brown, black chernozemic and dark grey chernozemic/luvisolic soil zones at a mid-latitudinal location within each zone. At each location soil will be excavated from three (3) trenches. Within each trench, two (2) or three (3) soil columns will be sampled (*i.e.,* n = 6 or 9 at each location). This design will ensure the frequency of sampling within a given area is higher, thus providing more confidence in the measure of variability at a given location.

Data will be collected from each soil column using similar methods outlined in Potapov *et al*. (2017). The maximum observed rooting depth will be identified and recorded. Samples will be taken every 10 cm from the maximum observed rooting depth to the top of the soil column sing a soil corer of known volume. Additional samples will be obtained below the maximum observed rooting depth to evaluate biological activity below the rooting zone. Soil invertebrates and root biomass will be measured in soil cores and subsamples will be taken for analysis of soil carbon, microbial biomass and any other parameters of interest.

To reduce projects costs soil invertebrates and root biomass only need to be measured in the lower most soil cores to address the project objective. However, given the challenges and complexity associated with studying 1) deep roots and their function in ecosystems and 2) the abundance and vertical distribution of soil invertebrates, it is recommended to partner with a University on this project to leverage NSERC funding to complete the analysis for all soil depths. Partnering with a University will also enable easier access to several research stations where this evaluation may be completed such as the Roy Berg Kinsella Research Ranch (central parkland ecoregion - dark brown chernozemic soil zone), St. Albert Research Station (black chernozemic soil zone), University of Alberta Ellerslie Farm (black chernozemic soil zone, *etc.*).

A detailed proposal will be developed after consultation with the project steering committee.

9.2 Lab/Greenhouse Study

The number of studies associated with evaluating deep roots is incommensurate with those devoted to shallow roots (Pierret *et al*. 2016), therefore there remain significant knowledge gaps associated with understanding deep root function. There are even less studies evaluating the ecological effect of contaminants at or below, the effective or maximum rooting zone. This is due, in part to the fact that observing and measuring deep roots is challenging. Measuring and observing ecological effects associated with deep roots interacting with a COPC even more so.

Given the challenges associated with establishing a field study to evaluate the effects of salinity (NaCl) on plant health (both above and below ground) when found at various depths within the soil profile, a lab/greenhouse study is recommended. Given the lack of appropriate methodologies available to study deep roots accurately and consistently, there is a need to evaluate novel techniques to assess ecological endpoints. Regardless of the experimental method, based on the review completed in this project the experiment should include varying concentrations of NaCl (0, 4, 12 and 20 ds/m) at 3 (three) depths (100, 150, and 175 cm bgs). Three potential experimental options have been identified, the potential advantages and limitations of which are presented in Table 4.

Table 4: Lab/Greenhouse Experimental Options Identified for Evaluating the Effect of NaCl at or Below the Effective Rooting Zone.

Experimental Option	Advantages	Limitations
Utilize a biotron facility [such as the one that exists at Western University, Ontario] to evaluate treatment effects through visual inspection of roots in-situ	• Allows for observational analysis of roots as they develop • Ease of measurement of multiple parameters	• often limited by replication • still require destructive root sampling to measure treatment effects below ground
Establish a greenhouse and/or mesocosm experiment and utilize camera technology (root rhizotron camera) to evaluate treatment effects on roots in-situ	• In-situ measurement of root area to evaluate treatment effects • More representative of field conditions given the volume of the experimental unit required for rhizotron tube installation • Can be completed outdoors	• Often limited by replication • Constrained by the requirements for rhizotron tube installation (depth/angle of installation). • Requires a significant volume of soil material
Establish a small diameter soil column experiment, watered from the bottom to encourage deep rooting and utilize an industrial X-Ray CT Scanner[1] which is optimized for cylindrical columns to non-destructively assess treatment effects	• Non-destructive assessment of differences in root abundance, orientation, and potentially structure (uniformity) between treatments • Replicable	• Few studies in the literature that have utilized this technique to evaluate roots • Although InnoTech has previously trialed this technique on small pots, this is a relatively new approach for studying roots in-situ and would require a preliminary trial before setting up a full experiment.

[1] InnoTech Alberta Quantitative Imaging Center https://innotechalberta.ca/research-facilities/quantitative-imaging-centre/

Given the limitations of the first two options and the potential advantages of the third option it is recommended to complete a preliminary study to evaluate the appropriateness and effectiveness of evaluating deep root treatment effects utilizing a X Ray CT Scanner. Funding for the preliminary feasibility study utilizing the X-ray CT Scanner would be sought from government sources to evaluate the appropriateness of the technology for this application. Funding from industry would be requested to complete the full experiment pending successful result.

A detailed proposal will be developed after consultation with the project steering committee.

10.0 CONCLUSIONS

This project looked to establish a scientifically defensible depth at which the ecological direct soil contact pathway is applicable. Specifically, the project evaluated the depth at which the potential presence of biota is low (the depth of the biologically active zone) and the depth at which the majority of water and nutrient uptake is acquired (the effective root zone depth [ERZ]). These depths are an important consideration in the discussion of ecological direct soil contact because they are a prerequisite in describing contaminant exposure for ecological resources and in defining the potential transport mechanism for quantifying associated risk.

Using publicly sourced information (census data), nine species (alfalfa, barley, canola, durum wheat, hay/fodder, mixed grain, oats, peas and spring wheat) were found to represent more than 95% of the agricultural land use in the province. Of these species, alfalfa was the deepest rooting of the plants reviewed with an ERZ of approximately 1.5 m and a maximum rooting depth of 3.7 m.

One of the major data-gaps identified is the absence from literature of a quantitative evaluation of the interrelations between the ERZ depth and the biologically active zone as it pertains to contaminated site assessment. As such, validation of the ecological direct soil contact exclusion depth is an area of potential scientific advancement.

Sodium chloride (NaCl) is a highly mobile, readily bioavailable and common anthropogenic contaminant relating to oil and gas exploration; it also has well defined adverse physiological effects on crops. For these reasons, it was selected as a suitable COPC surrogate for validation of the ecological direct contact exclusion depth. Following detailed review of the salt sensitivity for the nine most prevalent crop species in Alberta, alfalfa was determined as having the lowest threshold for salts (low concentrations of soil-salinity exhibit measurable reductions in plant yield).

A quantitative agronomic receptor evaluation for direct soil contact pathway requires a suitable surrogate that is found throughout the province, is considered deep rooting, and is salt-sensitive. Based on the findings of this assessment, alfalfa would be a suitable surrogate selection.

Potential future advancement addressing the knowledge gaps identified for establishment of an ecological direct soil contact exclusion depth for salinity (NaCl) relating specifically to agricultural regions in Alberta include:

- validating the effective and maximum rooting depth for alfalfa and assessment of the correlation between abundance and vertical distribution of soil invertebrates as related to soil organic matter; and
- evaluation of the effects of salinity (NaCl) on plant health (both above and below ground) when found at various depths within the soil profile and specific to those depths within and below the ERZ.

11.0 ACKNOWLEDGEMENTS

This work was made possible by funding from Petroleum Technology Alliance Canada (PTAC)

12.0 CLOSURE

We trust that the report review provided has met the expectation of the Alberta Pulse Growers (APG) and we thank you for providing us with this opportunity. Should you have any questions, please call the undersigned at 403.592.6180.

Yours truly,

Millennium EMS Solutions Ltd. (MEMS) & InnoTech Alberta (InnoTech)

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