SALT AFFECTED SOILS
WELL SITE RECLAMATION IMPLICATIONS

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EXECUTIVE SUMMARY

Salt affected soils are those in which salts interfere with normal plant growth. Excessive salt concentrations in soil are one of the major causes of decline in agricultural productivity around the world. Salt affected soils occur naturally on the landscape. In the agriculturally rich prairie regions of Canada, 30 % of the land area is estimated to have salinity or be at risk of salinization and 3.3 % of the land area is considered to be severely saline. Salt affected soils are classified as saline, saline-sodic and sodic, based on amount of salts, type of salts, amount of sodium and soil alkalinity.

Salt affected soils are can be caused by anthropogenic activities such as excessive irrigation, application of organic amendments, road salt runoff, mining and oil and gas exploration and development. Salt affected soils in Alberta must be remediated to meet government criteria for topsoil and subsoil horizons. The criteria are based on soil electrical conductivity and sodium adsorption ratio. Applicability of these salinity measures and values for all salt affected soils in the province and their relationship to successful remediation and reclamation is questioned. Observations in the field suggest successful reclamation can occur on salt affected soils that do not meet current criteria. The Petroleum Technology Alliance Canada (PTAC) contracted the University of Alberta to review and assess the available scientific literature on salt affected soils to evaluate against current regulatory requirements, to identify knowledge gaps in the science, to provide recommendations on the scientific validity of current remediation guidelines in Alberta, and to make recommendations for an alternative approach to reclamation of these salt affected soils. This report was written to provide a scientific basis for potential development of a new risk based assessment system for salt affected soil in Alberta.

Salts, whether natural or a result of anthropogenic activity, can change soil physical, chemical and microbiological properties. How they change soil properties and the magnitude of the change depends on type and concentration of salts. Sodium chloride is one of the most common salts, however, other chloride salts and sulfate salts can be present. Saline soils are those that have high electrical conductivities while sodic soils are those that have high sodium content; both can have detrimental effects on soil, water and plants. High sodium concentrations can cause clay swelling and lead to poor soil structure and reduced permeability.

Phytotoxicity of salt affected soils on species of agronomic importance has been well researched. In general, most common cereal and grain crops in Alberta are not considered salt tolerant. Little research has been conducted on effect of salts on native plants, particularly in prairie and mixedwood regions. Current salinity tolerance indices have been developed for crops based on predetermined and subjective acceptable losses in grain or biomass yields which may not be appropriate for native plant communities. Plant response to salts in soil is physiologically complex and at cellular, organismal and whole plant levels. Germination is one of the plant development stages most sensitive to salinity. Uptake of sodium and transport to shoots is the primary cause of decline in plant health. Plants may not have visual signs of salt stress immediately, even though physiological effects are occurring. Long term, potentially over multiple years, some plant species may not survive. Most plants are more sensitive to chloride than sulfate. Halophytes are naturally tolerant of salinity and are found in naturally saline communities in prairie and boreal regions. However, number of species and diversity is limited.

There are a multitude of factors that influence plant response to salt affected soils including species, cultivar, providence, climate, precipitation, soil texture, soil water content, land management, type of salt, stage of development at application or contamination and plant response measure. Therefore, salt tolerance is a relative, not absolute, term. At one site with a specific type of contamination a plant species may be salt tolerant; However, at another site with the same contaminant, it may not be salt tolerant.

A variety of remediation methods have been employed to reduce soil salinity. Leaching is the most common approach and in a short period of time can make surface soil hospitable for plant establishment and growth. Amendments such as calcium and organic materials assist in alleviating poor soil properties caused by salts in the upper soil layers. Fertilizer can reduce negative effects of salts on plants by addressing nutrient deficiencies. Phytoremediation is a growing field of study, which involves use of halophytic plants to uptake sodium, reducing soil salinity. Plant growth promoting rhizobacteria can accelerate these processes. Subsoil salinity, however, is more difficult to address with current remediation options. Even if surface soil is successfully remediated, salts may remain in subsoil layers and rise to the surface under some environmental conditions.

Based on available scientific data, current guidelines for acceptable electrical conductivity values on reclaimed sites are not supported. Depending on type of salt, concentration, soil type, hydrologic regime and plant species, successful surface soil reclamation may be achieved at lower or higher values. Ranges of values are recommended versus absolute criteria. Guidelines for specific salts to be used in conjunction with electrical conductivity values may be worth investigating, as occurs in British Columbia. Based on studies reviewed, no conclusions can be drawn regarding effectiveness of the guidelines for subsoil salinity or effectiveness of current sodium adsorption ratio guidelines for surface or subsoil. The exception is that in boreal ecosystems, high electrical conductivity and sodium adsorption ratios at depth were not detrimental to trees in the short term. We recommend an experimental and scientifically rigourous approach to future research to address knowledge gaps.

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1. INTRODUCTION

1.1. Background

Salt affected soils are those in which salts interfere with normal plant growth and development (FAO 2016). Salt affected soils are classified as saline, saline-sodic and sodic, based on amount of salts, type of salts, amount of sodium and soil alkalinity. Salt affected soils can develop naturally, or through anthropogenic means, such as oil and gas well site activities.

Western Canada is rich in natural gas and oil resources and as demand for these resources continues to grow, oil and gas development on the landscape will continue. In Alberta, approximately 88 % of the land base contains oil and gas reserves. Alberta currently has over 400,000 well sites (Alberta Energy Regulator 2016) and over 400,000 km of pipelines (Natural Resources Canada 2014) with many of them located in salt affected soils of the province. Associated facilities on the landscape include roads, batteries and pipelines.

Contamination of soil with salts is a common environmental problem following oil and gas production and has been documented in numerous publications. Oil and gas production results in highly saline waste water that must be disposed of in an environmentally appropriate manner. Produced water, or brine, generally contains chloride salts such as sodium chloride, calcium chloride or potassium chloride. The specific composition of produced water is affected by site geomorphological and soil properties. In western Canada, most produced water contains sodium chloride. Chloride molecules do not bind to soil and rapidly leach into deeper soil horizons and eventually to ground water. Sodium molecules bind with soil, causing clay dispersion and breakdown of soil structure. Spills of this produced water on site or during transportation are not uncommon and can result in plant mortality and long term soil and shallow ground water contamination.

Government regulations require remediation of salt affected soils before further reclamation can occur. Prior to 2004, reclamation was directed by the Salt Contamination Assessment and Remediation Guidelines (Alberta Environment 2001). Since 2004, remediation has been guided by Alberta Tier 1 and Tier 2 Soil and Groundwater Remediation Guidelines (Alberta Government 2016a). Most plants cannot tolerate high concentrations of salts in soil as they affect many plant physiological processes. Various remediation methods can be employed, depending on severity and distribution of the contamination and budget for the project. The most common methods are excavation and removal, leaching and addition of soil amendments. Remediation is considered successful when soil meets the guidelines for salinity and sodicity. In Alberta, salinity is measured as electrical conductivity (EC) and sodicity as sodium adsorption ratio (SAR). Both are important for reestablishment of functioning soil and plant communities.

After reclamation, much of the land contaminated by salt released from the oil and gas industry will be returned to agricultural cultivation or rangeland in the south and central parts of the province and to forest in the north. Region of the province is a major factor in determining remediation and reclamation methods for salt contamination. Leaching is often not feasible in southern arid regions due to lack of fresh water; excavation and removal are not economical for remote northern areas due to the expense associated with long hauling distances to proper disposal sites. Considerable research on salt contaminated sites has shown that both native and non native plant species can tolerate salt affected soils to varying degrees and that some species can even thrive on them.

Alberta has many naturally saline soils with an estimated 5 % of the total area under cultivation in the province affected by salinity (Alberta Agriculture, Food and Rural Development 2013). Thus, natural attenuation and/or modifications to reclamation guidelines may be appropriate on some of these disturbed sites. However, current regulations require both soil electrical conductivity and sodium adsorption ratio to be below criteria, even if a self sustaining desired vegetation cover exists. In some of these cases electrical conductivity and/or sodium adsorption ratio may be below values found on naturally saline sites. The historical approach of using the same criteria values for all sites and situations has been partially addressed through the current guidelines. However, other measures such as chloride concentrations, soil structural properties and/or plant abundances, may serve as appropriate indicators of detrimental salt contamination to better address soil remediation and reclamation.

1.2. Report Objectives And Methods

This report was written to provide a scientific basis for potential development of a new risk based assessment system for salt affected soil in Alberta. The Petroleum Technology Alliance of Canada (PTAC) contracted the University of Alberta to review and assess the available scientific literature on salt affected soils to evaluate against current regulatory requirements, to identify knowledge gaps in the science, to provide recommendations on the scientific validity of current remediation guidelines in Alberta, and to make recommendations for an alternative approach to reclamation of these salt affected soils.

This report is not meant to be an all inclusive document on salt affected soils. There are literally thousands of published papers and documents pertaining to the topic. However, each of these aspects of the topic is covered in sufficient depth to draw conclusions about the state of the science and to identify knowledge gaps relevant to the objectives.

University, government and industry library databases were searched. Web databases (eg Web of Science, BIOSIS Previews, Google Scholar) were searched for peer reviewed literature. Reference lists found in procured papers, graduate student theses and dissertations were reviewed to further expand the document search. The focus of the literature search was on manuscripts with scientifically documented impacts of salt contamination on soil and/or vegetation. The primary focus was on Alberta; however, this was expanded to include western Canada and the western United States as these regions have similar climate and soil conditions as some areas of Alberta and results are relevant to the objectives of this report. There was a focus on the oil and gas industry; however, this was also expanded to include other sources of salt contamination as impacts on soil and vegetation in Alberta would be similar.

Non peer reviewed literature from industry, consulting and government reports that provided information on the impacts of salts on soil and vegetation were reviewed. Current and historical provincial government regulations on salt contamination were reviewed to assess development of requirements to date. Some verbal discussions were undertaken with knowledgeable individuals from industry, government and academia, specifically aimed at locating any existing information or documents that might be useful in addressing questions within the scope of this literature review and analysis.

The literature review included works on native and non native plant species. Plant nomenclature for this report follows Moss (1983) and origin of plant species follows the Alberta Conservation and Management Information System (2016). Common names are used throughout the report. Many scientific names were not included in documents, thus there is low confidence in species referred to by common name alone.

The report is structured to address the objectives. The current regulatory framework for salt contaminated soils in Alberta is summarized. Potential impacts of salt contamination resulting from conventional oil and gas development, oil sands mining, road maintenance and agriculture on soil and vegetation are summarized. Salt tolerances, based on electrical conductivity and sodium adsorption ratio, of native and non native plant species in Alberta are provided. Based on the literature, current remediation guidelines in Alberta are evaluated and recommendations proposed for development of a more scientifically based approach. Gaps in knowledge are identified and future research to substantiate remediation requirements proposed.

2. REGULATORY FRAMEWORK

2.1. Alberta

Legislation governing reclamation in Alberta is the Environmental Protection and Enhancement Act (EPEA) (Alberta Government 2014a). Remediation of salt affected land, like any contaminated land, must meet the requirements of EPEA. Under EPEA, the Minister may establish guidelines for reclamation. The Conservation and Reclamation Regulation requires disturbed lands to be reclaimed to an equivalent land capability (Alberta Government 2014b).

In Alberta, the framework for management of contaminated sites is expected to prevent pollution, protect the health of humans and the environment and return land to productive use. Contaminant remediation for a site can follow a criteria or guideline based approach through direct adoption of accepted soil remediation guidelines. Alternatively, a site specific risk assessment, or exposure control, approach may be followed. A site specific based approach consists of an evaluation of exposure potential and hazard to receptors and the resulting risk to receptors at the specific site.

Alberta Tier 1 Soil and Groundwater Remediation Guidelines (Tier 1 guidelines) provide generic remediation guidelines for achieving equivalent land capability (Alberta Government 2016a). Tier 1 guidelines were developed to protect sensitive sites and can be used without modification at most contaminated sites in Alberta. They provide numerical targets for remediation of contaminated soil, and use of the values requires little site information. Tier 1 guidelines were based on identification of receptors to be protected under different land uses, applicable exposure pathways and parameters that allow conservative predictions of risks. Assessment of a contaminated site has specific minimum requirements. Land use and sensitivity factors include site description, land use, proximity to surface and drinking water supplies, actual and potential ground water uses and human and ecological receptors. Physical factors include soil particle size, stratigraphy and properties of surficial materials, depth to ground water and presence and types of buildings and structures. Contaminant characteristics and distribution include contaminant characterization and horizontal and vertical extent of contamination.

Tier 1 guidelines are meant to be used with several other government documents. Documents applicable to this report are associated with landfill disposal or remediation of sulfur containing soils, salt contamination assessment and remediation and drilling waste disposal. Topsoil guidelines for electrical conductivity and sodium adsorption ratio must be applied to L, F, H, O and A soil horizons or equivalent surficial material where these horizons do not exist. Subsoil guidelines may be applied below the A horizon or equivalent in lieu of topsoil guidelines.

Land use is an important factor in the Tier 1 guidelines since it impacts potential receptors and their exposure to soil contaminants. Therefore, guidelines are developed for natural areas, agricultural, residential and parkland, and commercial and industrial lands. Tier 1 guidelines use electrical conductivity and sodium adsorption ratio values to determine whether sites are adequately reclaimed on native grasslands according to 2010 Reclamation Criteria for Wellsites and Associated Facilities for Native Grasslands (Alberta Government 2013a), on cultivated lands according to 2010 Reclamation Criteria for Wellsite and Associated Facilities for Cultivated (Alberta Government 2013b) and on forested lands according to 2010 Reclamation Criteria for Wellsite and Associated Facilities for Forested Lands (Alberta Government 2013c).

Site specific guidelines can be developed using Alberta Tier 2 Soil and Groundwater Remediation Guidelines (Tier 2 guidelines) (Alberta Government 2016b). They can be developed for sites where Tier 1 guidelines are unnecessarily conservative and can be based on site specific conditions and potential for human or ecological exposure to the specific parameter. Alternatively, site specific conditions may increase risks to a level that makes a Tier 1 approach unacceptable. Thus, based on sensitivity of the site, Tier 2 guidelines may be more or less restrictive than Tier 1 guidelines. Tier 1 and 2 options mainly differ in the amount of site specific information that is required. By using Tier 2 guidelines, adjustments can be made to Tier 1 parameters that are simple and based on stable, measured, site specific physical parameters such as soil properties, geological conditions, hydrogeology and distances to natural surface water bodies. This includes screening out specific exposure pathways.

Site conditions that may trigger use of Tier 2 guidelines include: a source of volatile contaminants within 30 cm of a building foundation; unique building features, including earthen floors or unusually low air exchange rates; sensitive receptors that are present but not accounted for in Tier 1 guidelines; ground water flow to stagnant water bodies; soil or ground water contamination within 10 m of a surface water body; very coarse textured materials enhancing ground water or vapor transport; contamination in fractured bedrock; a contaminant source length parallel to ground water flow greater than 10 meters; and organic soils (Alberta Government 2016b). Conditions that would preclude use of Tier 2 guidelines include: modified receptor characteristics and exposure frequencies and/or durations, except where it addresses more sensitive receptors or greater degrees of exposure than those associated with Tier 1 land or water use category; modified site specific parameters or assumptions that require administrative or institutional controls to remain valid; exclusion of exposure pathways that may become operative in the future under a particular land use or that requires management to ensure they remain inoperative; modifications based on point of exposure or exposure pathway measurements; modifications or exclusions that lead to any land or water use restriction; and site specific properties that are not accounted for in generic models.

More information is required about the site when proceeding under Tier 2 guidelines (Alberta Government 2016b) including: physical soil properties such as soil texture, organic carbon fraction, soil porosity and/or bulk density and soil water content; hydrogeological conditions such as depth to ground water, hydraulic conductivity, hydraulic gradient and vertical separation between lower limit of contaminated soil and ground water table; site dimensions and distances to receptors, contaminant source length and width; distance to fixed surface water bodies; distance between contaminant plume to a more sensitive land use; and distance between contaminant plume to a building that is more sensitive than assumed at Tier 1.

If a contaminant exceeds Tier 1 or 2 remediation guidelines, vertical and horizontal extent of the contaminant must be delineated. This information is required to determine an appropriate remediation and management approach. When assessing a site under Tier 1 or 2 guidelines, background concentration of a substance is measured. If they are greater than Tier 1 guidelines, remediation is set to background levels or levels determined under Tier 2 guidelines.

Exposure control involves risk management to control risks to human health and the environment through barriers or administrative controls that are based on site specific risk assessments (Alberta Government 2016a). This usually precludes active remediation. Exposure control is used for sites that require restrictions to typical activities considered under a given land use or require ongoing risk management.

Salt Contamination Assessment and Remediation Guidelines (Alberta Environment 2001) (salt guidelines) reiterate Tier 1 soil quality guidelines. Primary guidelines for assessing salt and sodium status of salt contaminated soils are adapted from Soil Quality Criteria Relative to Disturbance and Reclamation (Alberta Agriculture 1987). The Canadian Council of Ministers of the Environment Commercial / Industrial Criteria (CCME 1999) values for electrical conductivity and sodium adsorption ratio may be used at sites zoned for commercial or industrial use. Remediation to generic guidelines is expected for topsoil and subsoil, to a depth sufficient to prevent impact on the rooting zone or at which similar levels of naturally occurring salts are in control soils. If soil remediation at depth is not feasible, a risk assessment is necessary.

Soil Quality Criteria Relative to Disturbance and Reclamation (Alberta Agriculture 1987) were developed to provide physical, chemical and biological guidelines for evaluation of soil material suitability for revegetation. Guidelines are provided for three major regions of the province. The plains region includes the central plains and Peace River plains, with a predominantly agricultural land use; the eastern slopes region includes the lower and upper foothills and the Rocky Mountains to the British Columbia border; the northern forested region includes the remainder of the province. Application requires comparison with representative off site controls.

Soil Quality Criteria Relative to Disturbance and Reclamation provide the primary guidelines for assessing salt and sodium status of salt contaminated soil (Alberta Agriculture 1987). The document provides soil rating categories which include electrical conductivity and sodium adsorption ratio values for topsoil and subsoil. For unrestricted land use, electrical conductivity of topsoil is considered good, fair, poor and unsuitable at values of less than 2, 2 to 4, 4 to 8 and greater than 8 dS/m, respectively. For subsoil, these respective values are considered less than 3, 3 to 5, 5 to 10 and greater than 10. Sodium adsorption ratios for topsoil and subsoil rated good, fair, poor and unsuitable are less than 4, 4 to 8, 8 to 12 and greater than 12, respectively. The document notes that some plants are sensitive to salts at electrical conductivity less than 2 dS/m and material with sodium adsorption ratios of 12 to 20 may be rated as poor if soil texture is sandy loam or coarser and if saturation percentage is less than 100.

Canadian Council of Ministers of the Environment Commercial / Industrial Criteria (CCME 1999) state that electrical conductivity for commercial and industrial site soils cannot be higher than 4 dS/m, and sodium adsorption ratio cannot be higher than 12. If the site is later changed from commercial or industrial use, further remediation may be required to meet standards for the new specified land use. CCME environmental quality guidelines require electrical conductivity to be a maximum of 2 dS/m for agricultural and residential sites and a maximum of 4 dS/m for commercial or industrial sites. Maximum sodium adsorption ratio values under CCME guidelines are 5 for agricultural and residential or parkland sites.

Other government documents relevant to regulatory requirements associated with salt contamination are summarized in Salt Contamination Assessment and Remediation Guidelines. Documents include Canadian Environmental Quality Guidelines; Interim Canadian Environmental Quality Criteria for Contaminated Sites; Guide 50 Drilling Waste Management; Guide 58 Oilfield Waste Management Requirements for the Upstream Petroleum Industry; Guide 55 Storage Requirements for the Upstream Petroleum Industry; Guide 51 Injection and Disposal Wells; Information Letter 98-2 Suspension, Abandonment, Decontamination and Surface Land Reclamation of Upstream Oil and Gas Facilities; Information Letter 99-5 Elimination of the Surface Release of Produced Water; Phase I Environmental Site Assessment Guideline for Upstream Oil and Gas Sites; Guidance for Use of the Phase I Environmental Site Assessment Guideline for Upstream Oil and Gas Sites; Guideline for Monitoring and Management of Soil Contamination Under EPEA Approvals; and Reclamation Criteria for Wellsites and Associated Facilities - 1995 Update.

2.2. Other Jurisdictions

2.2.1. British Columbia

In British Columbia, governing legislation for reclamation and remediation of a disturbed site is the Contaminated Sites Regulation (Government of British Columbia 2015). Soil standards have been established for sodium and chloride for human health and environmental protection. Land use is considered, including agricultural, urban park, residential, commercial and industrial. The sodium ion value for environmental protection for agricultural, urban park and residential lands is 200 ug/g, and for commercial and industrial lands is 1000 ug/g. The chloride ion value for environmental protection for agricultural, urban park and residential lands is 350 ug/g, and for commercial and industrial lands is 2500 ug/g.

2.2.2. Saskatchewan

Under the Saskatchewan Upstream Petroleum Sites Remediation Guidelines (Saskatchewan Petroleum Industry and Government Environmental Committee 2009), electrical conductivity and sodium adsorption ratio vary depending on specific land use factors, such as crop varieties, and site specific factors, such as climate and soil textures. Relative salt tolerance of various crops, including fiber, grain and special crops, vegetables and fruit crops and grasses and forage crops are provided. The threshold value was based on data provided by the United States Salinity Laboratory. Electrical conductivity for unconditional use is 2 dS/m for agricultural, residential and forest lands and 8 dS/m for subsoil. These values increase for moderately tolerant (3 to 5 dS/m) and tolerant (6 to 8 dS/m) crops; subsoil for both is 9 to 12 dS/m. Sodium adsorption ratio for unconditional use is 5 and for conditional use is 6 to 8; for subsoil these values are 8 and 9 to 13, respectively.

Guidelines provide common remediation criteria for the oil and gas industry, although intended for general guidance only and do not establish legal rights or obligations. They do not establish a binding norm nor prohibit alternatives not included in the document. The remediation criteria outlined are intended to protect human and environmental health and to restore the land to its pre-disturbance equivalent capability.

2.2.3. Ontario

The Ontario Ministry of Environment and Energy oversees reclamation and remediation of contaminated sites in Ontario. The Environmental Protection Act (Government of Ontario 1990) gives legislative authority to the ministry to manage incidences involving presence or discharge of a contaminant that creates an adverse effect or likelihood of an adverse effect. The Guideline for Use at Contaminated Sites in Ontario provides three approaches to disturbed site restoration, including background, generic and site specific risk assessment (Ministry of Environment and Energy 1997).

The background approach uses ambient or naturally occurring conditions or pre-contamination levels for agricultural and other land uses, which includes parkland, residential, industrial and commercial (Ministry of Environment and Energy 1997). Soil background electrical conductivity for agricultural use is 0.47 mS/cm, and 0.57 mS/cm for other land uses. The sodium adsorption ratio background value is 1.0 for agricultural land and 2.4 for all others. If criteria are not listed in the guideline, background data from a sampling program can be used for a site. Background criteria can be developed if those provided are not appropriate for the site.

The generic approach uses soil quality criteria developed to protect against adverse effects on human health, ecological health and the natural environment (Ministry of Environment and Energy 1997). Different assessments are required for sensitive areas, or if material at depth has been brought to the surface. Sensitive sites include nature reserves or nature reserve zones; a significant area of natural or scientific interest; an identified local environmentally sensitive area; fish habitat; habitat for vulnerable, threatened or endangered species of birds, wildlife, fish or plants; a wetland identified as significant; or a provincial park. It includes sites with less than 2 m of overburden and soil overlying bedrock or in the contaminant plume area down gradient of the source; and where inorganic chemical properties exceed background concentrations and soils have pH less than 5 or greater than 9 for surface soils or greater than 11 for subsurface soils.

The criteria identify two options for depth of soil restoration (Ministry of Environment and Energy 1997). For contamination at greater than 1.5 m below final site grade, either full depth or stratified restoration is acceptable. Stratified restoration uses criteria for soil at and above 1.5 m and below 1.5 m. The generic criteria for surface soil consider soil ingestion or dermal contact, terrestrial ecological protection and soil vapour to indoor air. The criteria consider whether soils are coarse or fine textured for some parameters. Values for coarse textured soils are generally smaller as contaminants that adhere to coarse material are usually more available than those that adhere to fine material. Electrical conductivity and sodium adsorption ratio do not vary by soil texture, only land use. Generic criteria are used if surface soil pH is 5 to 9 and when overburden greater than 1.5 m below surface has pH 5 to 11. The site specific risk assessment approach does not use existing soil quality criteria, but establishes criteria for a specific site.

3. SALT AFFECTED SOILS

3.1. Salt Affected Soils

Salt affected soils are those in which salts interfere with normal plant growth (FAO 2016). Salt affected soils are classified as saline, saline-sodic and sodic, based on amount of salts, type of salts, amount of sodium and soil alkalinity. Salt affected soils can develop naturally, or through anthropogenic means, such as oil and gas well site activities or other types of disturbances.

Salt affected soils contain significant quantities of inorganic soluble elements or compounds in the aqueous phase (Corwin 2003). The most common salts in soils include sodium (Na^{+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}) and sulfate (SO_4^{2-}) (Allison et al 1954, Miller and Curtin 2008). Other salts, usually present in soil in smaller quantities, include potassium (K^{+}), bicarbonate (HCO_3^{-}), carbonate (CO_3^{2-}) and nitrate (NO_3^{-}) (Allison et al 1954). In central and eastern Alberta, sodium sulphate is the dominant soluble salt (VanderPluym and Harron 1992); bicarbonate and chloride salts are found in smaller amounts.

A saline soil is generally considered to have electrical conductivity greater than 4 dS/m, exchangeable sodium percentage less than 15 and sodium adsorption ratio less than 13 (Jordan et al 2004). Alberta Agriculture and Forestry (2016) rate saline soils as non saline, weakly saline, moderately saline, strongly saline and very strongly saline. For salinity ratings at 0 to 60 cm depth in soils, electrical conductivity is less than 2, 2 to 4, 4 to 8, 8 to 16 and greater than 16 dS/m, respectively. At 60 to 120 cm soil depth, electrical conductivity for these same salinity ratings is less than 4, 4 to 8, 8 to 16, 16 to 24 and greater than 24, respectively.

Saline soils typically have pH less than 8.5 and may be referred to as white alkali soils due to visible salts at the soil surface (Allison et al 1954, Brady and Weil 2008). In the past, soils with electrical conductivity greater than 4 dS/m and exchangeable sodium percentage greater than 15 were called saline-alkali soils (Jordan et al 2004). The term alkali was replaced with sodic by 1979 (Jordan et al 2004). Soils with exchangeable sodium percentage greater than 15, pH greater than 8.3 and soluble bicarbonate and carbonate are now considered alkali (Gupta and Abrol 1990, Jordan et al 2004). Over time, sodic soils develop characteristic features. Downward movement of dispersed clay particles causes the soil surface to be coarse and underlain by an area of low permeability with a columnar or prismatic structure (Allison et al 1954). Sodic soils generally have pH 8.5 to 10.0 due to increased hydrolysis and formation of sodium hydroxide (NaOH). Sodic soils can be referred to as black alkali soils due to dispersion and visible accumulation of organic matter at the surface (Allison et al 1954, Brady and Weil 2008). Although sodic soils are defined as having exchangeable sodium percentage greater than 15, soil properties change gradually with increasing sodium, not at abrupt thresholds.

Salts are relatively mobile and can move easily within the soil profile; positive ions are typically less mobile than negative ions due to their participation in cation exchange reactions on soil surfaces (Alberta Environment 2001). Soluble salts generally move downward but can move in any direction by leaching through the soil, by capillary action (Landsburg 1981) or by chemical diffusion (Merrill et al 1980). Amount and rate of downward leaching of soluble salts depends on water available to leach through the soil profile and soil hydraulic conductivity, which is mainly a function of soil texture (clay content) and saturating cations (mainly sodium). Capillary action can move salts with pore water upward into the root zone from a high water table. Salinization of root zone soil by capillary action is affected by amount of capillary rise in soil and depth to water table (Finlayson 1993). Movement of soluble salts by chemical diffusion can occur when non saline and non sodic soil has been replaced over strongly saline spoil materials, such as in strip mining (Merrill et al 1980). Movement by chemical diffusion generally occurs within 30 cm above the soil and saline spoil interface. Salinization by chemical diffusion is affected by sharpness of gradient between non saline soils and underlying strongly saline spoil materials and hydraulic conductivity of materials (Finlayson 1993). Salt movement can occur when saline soil pore water moves through soil in response to a temperature gradient, resulting in upward movement of salt during winter, as soil water tends to move from warmer areas at lower depths to the cooler freezing front near the soil surface (Cary and Mayland 1972, Landsburg 1981).

These mechanisms of salt movement can result in seasonal fluctuations in soil salinity (Finlayson 1993) and considerable within year variation of soil salinity levels (Graveland 1970, Landsburg 1981, Buckland and Hendry 1992, Miller and Read 1992). For example, Landsburg (1981) found soil electrical conductivity varied by more than 2 dS/m at various depths during the year, with measurements taken weekly during the frost free period.

3.2. Sources And Occurrence

Salts can be naturally occurring in the soil profile. Salts are present in the structure of primary minerals of soil parent material (Allison et al 1954, Jordan et al 2004). Weathering of minerals causes salts to be solubilized, resulting in primary or fossil salinity (Allison et al 1954, Qadir and Oster 2004). Salts can be from ancient marine deposits, drainage basins or inland seas (Allison et al 1954, Jordan et al 2004). Salts may come from ocean water or spray in coastal regions. Surface water can be a source of salts during flooding and ground water can be a source of salts when it rises through the soil profile to the surface. The amount of salt brought by surface and ground water depends on salt content of the material which water has been in contact with.

Factors contributing to soil salinization include water deficit, topography, salt content in parent material and hydrology (Wiebe et al 2007). Soil salinity is typically a concern in areas with arid or semiarid climates (Jordan et al 2004). Dry areas have insufficient precipitation for complete leaching and high rates of evaporation (Allison et al 1954). Saline soils do not usually occur in humid regions because any salts in the soil are leached down the profile, where they ultimately enter the ground water and are transported to streams, lakes or oceans (Allison et al 1954). Areas subjected to restricted drainage can often become saline (Jordan et al 2004). Drainage can be restricted due to a high water table or low soil permeability (Allison et al 1954).

Hydrologically isolated basins with no outlet are common in dry regions. They receive salt containing water from higher areas which collects and raises the water table or ponds on the soil surface. Evapotranspiration of this water leaves salts in the soil. Low soil permeability can be caused by fine soil texture, poor soil structure or soil compaction. Soils in low landscape positions have a greater risk of salinization because water will more likely reach the soil surface and leave salts upon evaporation (Jordan et al 2004). Anthropogenic activities associated with salt contamination include irrigation, oil and gas production, salt processing and road maintenance storage, rendering and use of saline material for industrial purposes (Alberta Environment 2001, Jordan et al 2004).

Two general forms of salinity are dry land salinity and salinity due to irrigation. In dry land salinity the water table is typically two to three meters below the soil surface. Ground water salts are raised by capillary action to the soil surface. If this ground water is saline, and if farming practices on this land allow more rain or snow melt to enter the aquifer than it can contain, then capillary action coupled with evaporation will result in a salt crust developing on the soil surface. Irrigation induced salinity will occur over time because nearly all irrigation waters contain dissolved salts which accumulate in the rooting zone as crops make use of soil water. These accumulated salts must be leached out of the rooting zone by sufficient additional irrigation, otherwise that land will eventually be unsuitable for crop production due to salinity.

When water percolates through the soil, salts are dissolved from the soil matrix and transported to ground water (Wiebe et al 2007). Depressions typically have shallow ground water tables which allow ground water to be drawn up through the soil resulting in salt deposits at the surface when water evaporates. Water containing salts also moves laterally outwards from depressions with standing water leaving salt rings. Cultivation of annual crops uses less water than native grassland ecosystems resulting in elevated water tables and greater salinization risk.

Alberta Agriculture and Forestry (2000) classified seven types of saline seeps based on cause. In contact saline seeps ground water flows in a permeable layer above a less permeable layer until the permeable layer thins. This forces ground water flow close to the surface; water rises to the surface, evaporates and a saline seep forms. In slope change salinity, ground water flows in a permeable surface layer above a less permeable layer until surface slope decreases, forcing ground water close to the surface, where it evaporates and a saline seep forms. Slope change seeps expand upslope. Outcrop salinity occurs where a permeable, water bearing layer outcrops at or near the soil surface. These seeps often occur in rows along a slope at similar elevations. Artesian salinity occurs where water from a pressurized aquifer rises to or near the ground surface and is usually associated with intermediate or regional ground water flow systems. If pressure is high enough, water flows to the surface and produces a flowing well, spring or soap hole. Depression bottom salinity occurs in depressions and water courses with poor drainage, particularly rolling and hummocky areas. Water flows over the ground surface, ponding in low lying areas until it drains or infiltrates. Ground water at the edge of the pond moves upslope through the upper soil layer, rises to the surface and evaporates, after which water from the water table rises to the surface in the previously ponded area. Coulee bottom salinity forms in bottoms of coulees and water courses similar to depression bottom salinity but on a larger scale. Slough ring salinity occurs as a ring of salt around a permanent water body. Some water infiltrates from the water body into the permeable upper soil layer and moves upslope. Water from upslope flow and the water table rise to the soil surface and evaporate, leaving salts behind.

In the Canadian prairies approximately 20 million ha (30 %) of land are saline or at risk of becoming saline (Steppuhn 2013a). Approximately 18 million ha of agricultural land are prone to salinization. There are 2.23 million ha of severely saline land that have electrical conductivity greater than 5 dS/m and that could result in non irrigated crop yields being reduced by at least 25 %. Approximately 2.2 million ha of land have visible dryland salinity, 1 million ha of agricultural land at 0 to 60 cm depth is moderately to severely saline, and 3.5 million ha of agricultural subsoil is moderately to severely saline (Wiebe et al 2007).

Salt affected soils can be found throughout Alberta, but mainly occur in the south and southeast, from the American border to Edmonton and from Calgary to the Saskatchewan border (Alberta Agriculture, Food and Rural Development and Agriculture and Agrifood Canada 2016). Areas with over 30 % of soil being salt affected are present east of Red Deer. Outside of the prairies, salt affected areas occur near Grande Prairie, Peace River and Fort Vermilion. Changes in land management in Alberta from 1981 to 2005 resulted in an increase of 1.4 million ha in the very low risk of salinization class, a decrease of 0.44 million ha in the moderate risk class, a decrease of 0.64 million ha in the low risk class, and a decrease of 0.32 million ha in the high and very high risk classes (Wiebe et al 2007).

Parent material in the area of Alberta bounded by Vulcan, High River, Calgary and Gleichen has relatively high salt concentrations (Greenlee et al 1968). Seepage has resulted in salt affected soils with decreased agricultural productivity. This area has high evapotranspiration due to relatively low annual precipitation as rainfall (430 mm), high winds (16 km/h) and high amounts of sunlight. Salt generally accumulates on hill slopes, in road cuts and in depressions. Soils low in salts (orthic dark brown chernozems) are typically found on upper slope positions and where bedrock occurs at greater depths. Saline dark brown chernozems are found in seepage areas at upper and mid slope positions. Saline humic gleysols are found at lower slope positions and in depressions at high elevations. Dark brown solonetz soils were resalinized to the surface and found in depressions at low elevations.

3.3. Effects Of Salts On Soil Physical And Chemical Properties

Salt contamination can impact several environmental components and ecological processes. It can degrade soil chemical properties, impair vegetation, degrade soil physical properties by excess sodium, and degrade surface water or ground water quality. Hivon and Sego (1995) report a significant reduction in soil strength with increased salinity and temperature.

Soil is affected by sodium. Although calcium and magnesium are preferentially adsorbed over sodium, when sodium dominates the soil solution in sodic soils, it replaces calcium and magnesium on adsorption sites (Allison et al 1954). Sodium is a monovalent cation which causes dispersion of soil particles (Jordan et al 2004) because its low valency increases diffuse double layer thickness and forces soil particles away from each other (Quirk 2001). Sodium induced dispersion can cause soil structure issues such as swelling, surface crusting and hard setting (Qadir and Oster 2004). Clay particle swelling causes large pores to decrease; resulting dispersion and movement of clay platelets further blocks soil pores, which can decrease water infiltration and air movement into and within the soil profile, reducing plant available water and increasing runoff and erosion (Shainberg 1990, Jordan et al 2004, Qadir and Oster 2004). Soil dispersion affects hydraulic conductivity by causing loss of soil structure. If water cannot pass through soil, the upper layer can swell and become water logged, resulting in anaerobicity which can decrease organic matter decomposition rates. When soil is wet and dried repeatedly and clay dispersion occurs, it reforms and solidifies into cement like crusts with little or no structure. Excess sodium can decrease soil tilth, its ability to cluster into easily crumbled masses of particles (Warrance et al 2016). A sand textured soil, with relatively large, loose particles, easily absorbs and drains water; thus, salt in sand textured soil can be leached easier.

Swelling of clay is greatly affected by clay mineralogy, the ionic species adsorbed on clay surfaces and electrolyte concentration in solution (Goldberg and Glaubig 1987). Swelling is greatest for smectite clays that are sodium saturated. As electrolyte concentration decreases, clay swelling increases. If exchangeable sodium percentage increases above 15, swelling clays (montmorillonite) will retain a greater volume of water. Both hydraulic conductivity and permeability decrease as exchangeable sodium percentage increases and salt concentration decreases (McNeal and Coleman 1966).

Soil water salinity can affect soil physical properties by causing fine soil particles to bind together or flocculate into aggregates (Warrance et al 2016). Although increasing soil solution salinity has a positive effect on soil aggregation and stabilization, at high levels it can have negative effects on many plant species. Salts that contribute to salinity, such as calcium and magnesium, are small and tend to cluster close to clay particles. Calcium and magnesium will generally keep soil flocculated because they compete for the same spaces as sodium to bind to clay particles. Increased calcium and magnesium concentrations can reduce the amount of sodium induced dispersion in a soil.

Saline sodic soils remain flocculated as multivalent cations in soil solution prevent particle dispersion caused by sodium (Allison et al 1954). The high ionic concentration of the soil solution and high charge of the multivalent cations compress the diffuse double layer and allow soil particles to remain close together (Quirk 2001).

The ratio of salinity (electrical conductivity) to sodicity (sodium adsorption ratio) determines effects of salts and sodium on soils (Warrance et al 2016). Salinity promotes soil flocculation and sodicity promotes soil dispersion. Combinations are measured by the swelling factor; amount soil will likely swell with different salinity and sodicity combinations. It predicts if sodium induced dispersion or salinity induced flocculation will most affect soil physical properties.

Salinity reduces ground water quality and may cause it to be unsuitable for uses such as irrigation and consumption by humans or other organisms. Ground water may transport saline water to fresh water systems where it can potentially impact aquatic organisms. Soil salinity that results in clay dispersion can cause dispersed particles to move with percolating waters deeper into the profile, which can result in deeper clay deposition and formation of clay pans in the soil.

4. EFFECTS OF SALTS ON SOIL MICROORGANISMS AND ENZYMATIC ACTIVITIES

4.1. Bacteria And Fungi

Salt affected soils can impact microorganisms (Berg et al 2012). High concentrations of salts increase osmotic pressure potential of soil water, which can draw water out of microbial cells and they can be killed by plasmolysis (Yan et al 2015). Salinity tolerant microorganisms counter osmotic stress by making osmolytes that allow maintenance of cell turgor and metabolism. Making osmolytes costs energy; therefore, microorganisms have reduced growth and activity.

Microbial community composition may be affected by salinity (Pankhurst et al 2001, Gros et al 2003, Gennari et al 2007, Llamas et al 2008, Chowdhury et al 2011) since microbial genotypes differ in their tolerance of a low osmotic potential (Mandeel 2006, Llamas et al 2008). Low osmotic potential decreases spore germination and growth of hyphae and changes morphology (Juniper and Abbott 2006) and gene expression (Liang et al 2007), resulting in formation of spores with thick walls (Mandeel 2006). Fungi tend to be more sensitive to osmotic stress than bacteria (Pankhurst et al 2001, Sardinha et al 2003, Wichern et al 2006). Microorganisms adapt to osmotic stress through selective exclusion of the solute incorporated, thus accumulating the ions necessary for metabolism, or through production of organic compounds that antagonize the concentration gradient between the soil solution and the cell cytoplasm.

Wong et al (2008) evaluated effects of salinity and sodicity on microbial biomass and soil respiration. Highest soil respiration rates were in soils with low salinity and lowest in soils with medium salinity. Microbial biomass was greater with high salinity and lower with low salinity. This was attributed to a greater availability of substrate in high salt concentrations, by an increase in dispersion of soil aggregates, or from dissolution or hydrolysis of organic material in soil. High salinity can also reduce microbial biomass (Tripathi et al 2006, Wichern et al 2006), affect amino acid capture and protein synthesis and respiration (Laura 1974, Pathak and Rao 1998, Gennari et al 2007) and cause increases and decreases in carbon and nitrogen mineralization (Pathak and Rao 1998, Wichern et al 2006).

Since microbial biomass and activity are most relevant in the upper centimeters of soil; salinization close to the surface can significantly affect microbiologically mediated processes for ecological functions and fertility. Plant nutrient availability is regulated by microbial activity in the rhizosphere. Thus factors affecting this community and its functions also influence nutrient availability and plant growth. A microbial response with a significant role in plant growth is nitrogen recycling. Since nitrification can be inhibited in the presence of salts (Laura 1974, Sethi et al 1993) resulting in an accumulation of ammonium nitrogen, cycling of both forms of nitrogen will have a significant impact on nitrogen dynamics and availability for plants. Sodium chloride can reduce nitrogen immobilization, nitrification and mineralization (Azam and Ifzal 2006). Thus there is greater sensitivity to sodium chloride by microorganisms that have assimilated nitrate.

4.2. Mycorrhizae

Mycorrhizal fungal associations are important for establishment and survival of many native species. Identification of salt tolerant species is currently of interest as they may be used as pre-inoculants for plants used in revegetation of salt affected soils. Bois et al (2005) investigated the effect of sodium chloride contamination on five species of mycorrhizal fungi, two basidiomycetes and three ascomycetes. Ascomycetes were more tolerant of salt stress than basidiomycetes. Each species had different mechanisms of salt transport and resistance. *Rhizophagus irregularis* showed promise to develop in saline solutions, however, individual isolates had different tolerances (Campagnac and Khasa 2014). No spores germinated in consolidated tailings water which contained high concentrations of sodium, chloride and sulfate.

4.3. Enzymatic Activities

Soil enzymes carry out a fundamental role in ecosystems as catalysts of various reactions that result in organic residue decomposition, nutrient cycling and organic matter formation in soil. They generally originate with microorganisms but can also have animal and plant origins. Soil enzyme activity sensitivity to salinity varies.

Salinity, measured by electrical conductivity, negatively influenced soil enzyme activity, varying with enzyme and soil (Frankenberger and Bingham 1982, Ahmad and Khan 1988, Rietz and Haynes 2003). Dehydrogenase activity was severely inhibited and hydrolases mildly inhibited. Enzyme activity reduction in saline soils could be due to osmotic dehydration of microbial cells that liberate intracellular enzymes, which are vulnerable to attack by soil proteases, thus decreasing enzyme activity. The salting out effect modifies ionic conformation of the protein enzyme active site, and specific ionic toxicity causes a nutritional imbalance for microbial growth and subsequent enzyme synthesis. Ahmad and Khan (1988) and Rietz and Haynes (2003) obtained similar results. Increased salinity due to salt water can decrease carbon content of soil microbial biomass and enzymes (Rietz and Haynes 2003). Garcia and Hernandez (1996) and Ghollarata and Raiesi (2007) found increased soil salinity inhibited enzyme activities of benzoyl argininamide alkaline phosphatase and β-glucosidase and microbial respiration. Invertase, urease and nitrate reductase activities were severely reduced with increasing sodium chloride. Ahmed and Khan (1988) found amylase, catalase, urease and phosphatase activities declined with increasing salinity. Tripathi et al (2006, 2007) found dehydrogenase, β-glucosidase, urease and acid and alkaline phosphatases were adversely affected by salinity, with most extreme reactions in summer. Dehydrogenase activity was most affected.

5. SALT IMPACTS ON PLANTS

5.1. Rooting Zone

The rooting zone is the portion of soil profile containing plant roots. It varies with plant community and dominant species. In tundra with shallow organic soils, roots are limited to the upper 15 cm (Bryant and Scheinberg 1970); in mixed grass prairie the rooting zone is about 30 cm (Peltzer and Kochy 2001); in boreal forest is up to 3.5 m (Strong and La Roi 1983). Annual plant species tend to have shallower rooting zones than perennials, and shrubs have shallower rooting zones than trees (Schenk and Jackson 2002). Rooting zone depth is influenced by soil physical properties and annual precipitation (Schenk and Jackson 2002, MEMS 2013). The rooting zone is different from the rhizosphere, which is a subzone of soil surrounding plant roots, directly influenced by root secretions and associated microorganisms.

5.2. Plant Uptake Of Salts

Toxicity is related to bioavailability and solubility of potential contaminants. Soluble constituents in the plant rooting zone such as macro and micro nutrients, including salts, are regularly transported into plant roots. Some salts are readily transported, such as sodium; others which bind to soil particles, such as chloride, are not. In an aqueous solution, salts enter plant roots and in low concentrations are benign. However, as salt concentrations increase plants may respond with reduced growth, yield and seed production and eventually plant mortality (Munns and Termaat 1986, Volkmar et al 1998). While salts enter through plant roots, it is their impact on plant leaves that ultimately determines if a plant lives or dies. Visual symptoms of salt stress are observed in leaves, such as changes in leaf colour, tip burn and marginal necrosis. Effects of salt stress are most prevalent in early stages of plant establishment and growth, with greatest effects during the period of maximal elongation in grasses (Volkmar et al 1998).

Plant response to salinity is one of the most widely studied fields of plant physiology (Francois and Maas 1978, 1985). The focus, however, has been on species of agricultural importance with a goal of better understand processes that make these plants tolerant of salinity so that more salt tolerant species can be selected for production (Munns 1993, Ashraf and Harris 2004). Most of this research has been conducted under controlled conditions. Plant response and tolerance to salt are physiologically complex and species dependent (Ashraf and Harris 2004). The salt stress mechanism varies depending on plant stage of development as organs grow and change and different genes are expressed. Salt stress mechanisms are also affected by salt concentration and environmental conditions which change over time. Salt concentrations in the rooting zone change with infiltration of water from rainfall or snow melt or due to loss of water by evapotranspiration (Steppuhn and Wall 1999).

Salt stress in plants is exhibited at multiple levels; cellular, organismal and whole plant (Munns and Termaat 1986). Cellular level salt stress primarily reduces or inhibits water uptake resulting in osmotic stress. Plants maintain an osmotic gradient, allowing soil water and soluble constituents to move between soil and roots. If soluble salt concentration in soil water increases, the osmotic gradient is reduced or eliminated, resulting in plant drought stress and nutrient deficiencies. Within hours leaf cells lose water, volume and turgor. Due to osmotic adjustment, the ability of plants to produce solute molecules (proline, mannitol, sorbitol) in the cytoplasm, cells will rebound. While cells recover, rate of cell elongation remains reduced due to drought stress. Other immediate effects include reduced elongation in new leaves and reduced stomatal conductance in mature leaves. Hot dry weather exacerbates effects of soil salinity and osmotic stress as plants need greater soil water, but salts reduce water uptake. While water stress can be significant in the long term, it does not directly impact plant growth in days or weeks.

Once salts enter plant roots, they are transported to leaves which can lead to ion toxicity (Munns and Termaat 1986). The rate by which salt ions are transported is a key factor in plant salt tolerance and closely linked to growth rate. When salts reach a leaf, they pass across the plasma membrane and are compartmentalized in cell vacuoles. The rate at which salts pass into the cell cannot exceed the rate of accumulation in vacuoles, or salts will enter cell cytoplasm. If this occurs, the osmotic gradient increases, causing water in the cell to move outward into intercellular space and leading to cell dehydration and eventual death. Thus, the rate of salt movement into the vacuole must continually match the rate of salt transport from root to leaf. The energy required by the plant to compartmentalize salts in vacuoles and to balance the osmotic gradient through synthesis of solutes in the cytoplasm means there is less energy for other plant functions. It is this accumulation of specific salts in the leaf that determines overall plant outcome. Specifically, salt accumulation in mature leaves is greater than in young leaves, causing them to die first, often the first sign of salt ion toxicity. Once the death rate in mature leaves reaches that of leaf expansion, photosynthesis is disrupted leading to reduction in carbohydrate production needed to support continued growth (Munns 1993).

Early researchers thought reduced cell turgor reduced growth in plants under salt stress due to reduced stomatal conductance and/or cell expansion. However, more recent research found this is not necessarily true (Munns 1993, Volkmar et al 1998). While leaf water stress has a negative impact on plants, it is not a limiting factor to shoot growth in saline soils in the short term (Munns and Termaat 1986). In a healthy growing plant, cell expansion will continue, increasing vacuole storage space for salt compartmentalization. When cell expansion is impaired by salts, or other environmental factors, the plant's capacity to tolerate the salts is impaired.

At the whole plant level, salt affected soils can alter growth and development. In crops, it can accelerate initiation of reproductive structures (Maas and Greive 1990, Greive et al 1994, Romero and Maranon 1994). Tiller development can be delayed with saline conditions, reducing grain yield in crops (Maas and Grieve 1990). Kernel mass may increase, with fewer produced (Maas and Greive 1990, Francois et al 1994). This alteration of growth leads to reduced photosynthetic rates and eventually to plant death.

Nutrient imbalances frequently result from salt stress. Sodium readily replaces calcium and potassium in plant tissue and reduces its transport and mobility to growing regions of the plant (Grattan and Grieve 1999). Salinity reduces phosphate availability in soil and therefore uptake and accumulation and presence of chloride in plants reduces nitrate uptake. Any nutrient deficiency can result in decreased plant yield, growth or health.

Roots are less affected by saline soil than shoots (Munns and Termaat 1986, Volkmar et al 1998). Thus, an increase in plant root to shoot ratio generally occurs under saline conditions. Water stress does not directly affect shoot growth, but may affect roots (Munns and Termaat 1986). Under low soil water potential roots may respond by sending an inhibitory signal to leaves, which in the short term decreases leaf expansion (Munns and Termaat 1986, Munns 1993). A two phase model of plant response to salinity consists of short and long term (Cramer and Bowman 1991, Yeo et al 1991, Munns 1993). Genotype will affect growth rate and response to salinity (Munns 1993). In the early phase, species may be affected similarly as the effect is from salt concentration outside the roots, relative to the later phase where individual plant abilities to adapt or tolerate increased salt concentrations in leaf tissue differs with species.

5.3. Salt Tolerance Mechanisms

While some plants are tolerant of salts, most are not. The processes of salt entry and transport through the plant system is the same in halophytes and glycophytes. However, halophytes can use the salts at a rate which prevents cell death and eventually whole plant death. Halophytes tend to be from specific plant families, mainly Chenopodaceae, Poaceae and Asteraceae (Dodd and Coupland 1966, Bradiek et al 1984, Vavrek et al 2004). Salt tolerance mechanisms in plants are not well understood, although they are reported to be plant species dependent. Some plants, such as maize, barley and tobacco, are able to make osmotic adjustments which help them to maintain cell turgor and cell volume. Some plant species exclude salts (Franklin and Zwiazek 2004, Renault 2012).

The three primary methods of salt tolerance (Volkmar et al 1998, Munns and Tester 2008) are osmotic stress tolerance, salt exclusion from shoots and tissue tolerance. Salt tolerance mechanisms occur at cellular and whole plant levels. While not well understood, recent research shows plant molecular sensors, hormones, enzymes and genes have an essential role in these mechanisms as they are responsible for stress sensing and signalling (Munns 2005, Horie et al 2012, Deinlein et al 2014). Recent research on mechanisms of salt tolerance in plants concedes that it is highly complex and physiological and biochemical indicators for individual species are needed (Ashraf 2004, Yamaguchi and Blumwald 2005, Nawaz et al 2010).

Osmotic adjustment, the process of balancing osmotic gradient by synthesizing solute molecules in the cytoplasm, allows plants to maintain cell turgor and volume under osmotic stress. Production of these solutes, however, is energy consuming and reduces other plant functions including growth. Hormones such as abscisic acid, gibberellins and proline may be central to root to shoot signaling of drought stress thereby triggering reduced plant growth and stomatal conductance. For example, production of the hormone abscisic acid (ABA) can prevent root elongation in highly saline environments. Calcium may be an important plant hyperosmotic sensor as it often rapidly increases in roots in the presence of sodium chloride.

Once concentrations of salt ions build up in the soil solution they mainly enter the root passively and either move back out into the soil solution or are compartmentalized in vacuoles of the outer root cells (Volkmar et al 1998, Munns and Tester 2008). These cells eventually cross the endodermis and release salts into the stelar apoplast which moves them to the xylem for transportation to shoots. Sodium can be readily replaced by potassium for uptake in some plants, reducing sodium concentrations in shoots. Halophytic species may preferentially select sodium over potassium, however, sodium-potassium discrimination is not a requirement for salt tolerance. Some glycophytes may appear to discriminate against sodium, although this is not due to enhanced discrimination but to ability to more effectively partition sodium arriving in the shoot. There is increasing evidence that the high affinity potassium transporter (HKT) family of genes may be responsible for retrieval of sodium from the xylem.

There are two morphological adaptations by which high salt concentrations are tolerated in leaf tissue, an increase in cell size due to increased vacuole volume or excretion of salts by glands or bladders (Volkmar et al 1998, Munns and Tester 2008). Succulence and salt glands, however, are not common in crop species or monocotyledons. The ability of some plants such as barley to regulate rate of salt transport into cell vacuoles also increases salt tolerance. Barley effectively partitions chloride into epidermal cells and potassium into mesophyll cells. The relative importance of each mechanism is species dependent but relies on time exposed to salts, salt concentration and environmental conditions, specifically soil water availability and air humidity. In general, salt exclusion from shoots while an important factor, at high salt concentrations, may be of less importance than the other two mechanisms.

5.4. Natural Saline Communities

A diversity of salts were found in naturally saline grassland soils in Alberta and Saskatchewan, although distribution of native and non native salt tolerant species did not depend on type of salt or concentration (Redmann and Fedec 1987). Alberta soils had higher electrical conductivity (23 to 75 dS/m) and sodium adsorption ratio (30 to 137) than Saskatchewan soils (electrical conductivity 7 to 60 dS/m; sodium adsorption ratio 4 to 54). Sodium had the highest concentration at all Alberta sites followed by sulfate; sulfate was highest at most sites in Saskatchewan followed by sodium. Chlorides were in high concentrations at only a few sites in Saskatchewan and one in Alberta. This supports other reports that sulfate salts dominate in southern Alberta (Chang et al 1983, Curtain et al 1993). Red swamp fire was found on the most saline sites and russian thistle and oak leaf goosefoot on the least saline sites. Tissue ion concentrations were significantly correlated with soil ion concentrations for only two species, common orache and kochia. This may be a concern for grazing lands.

A similar study of naturally saline sites with severe (white crusting on surface) salinity was conducted across Manitoba, Saskatchewan and Alberta (Braidek et al 1984). Dominant species across all sites were western sea blite (on 61 % of sites), kochia (45 %), nuttall's alkali grass (45 %), spear saltbush (45 %), foxtail barley (36 %), salt grass (36 %), spear orache (31 %), white heath aster (29 %) and perennial sow thistle (29 %). In a survey of saline soil in Saskatchewan grasslands, mean electrical conductivity in the most saline was 3.6 dS/m at 0 to 15 cm, decreasing with depth to 2.2 dS/m at 60 to 90 cm (Dodd and Coupland 1966). Dominant ions were sodium and magnesium with large amounts of chloride, sulfate and bicarbonates. Dominant plant species included red samphire, seaside arrow grass, nuttall's alkali grass, inland salt grass, foxtail barley and wheat grasses. A survey of a natural salt pan in Manitoba, found less than 2 % of plant species in the zone of highest salinity (total salts 78,400 mg/L) had mycorrhizal fungi associations, while greater than 40 % of plants did in the lower salinity zones (19,800 to 23,000 mg/L) (Johnson-Green et al 1995).

Much research has been conducted on natural saline communities in the boreal region of Alberta to better understand reclamation options in the Athabasca Oil Sands Region. Close et al (2007) found boreal forest saline sites were dominated by sodium (anions not analysed) and concluded that boreal species can tolerate topsoil electrical conductivity up to 4 dS/m on these sites. Based on number of live stems and merchantable timber, white spruce was not affected by electrical conductivity even with subsoil values as high as 23 dS/m. However, trembling aspen was affected, with declines in stem densities and merchantable timber increasing with salinity at all sites. Both species tolerated topsoil with sodium adsorption ratios greater than 12 and as little as 20 cm of topsoil was sufficient for productivity. Purdy et al (2005) found boreal forest communities could establish on saline soils as long as salinity was not high in the rooting zone. Twelve graminoids, 15 forbs and one shrub were classified as having an affinity to strongly saline sites (electrical conductivity 2 to 22 dS/m at 10 to 20 cm depth; 10 to 23 dS/m at 80 to 100 cm). These sites were dominated by sodium and chloride ions, although magnesium was also high. Plant composition was similar among communities established on sites with similar salinity. This is contrary to previous reports that boreal trees are sensitive to salinity (Howat 2000). Many species not common in the boreal forest but found on saline sites in more southern regions were abundant. Further studies were conducted to understand effect of subsoil salinity on aspen and white spruce (Lilles et al 2011). High salinity sites were dominated by chloride with concentrations between 1,000 mg/L and 7,000 mg/L at 50 to 100 cm depth; the exception was one site, where sulfate dominated with a concentration of ~1,300 mg/L. Basal growth of aspen was reduced by 50 % as salinity increased but white spruce growth was not affected. Aspen stands were merchantable with electrical conductivity of 7.8 dS/m at 50 to 100 cm and white spruce was not merchantable on most sites. Subsoil sodium adsorption ratio was greater than 13. Both species had reduced growth over time and were shallow rooted, which may limit long term productivity.

Naturally saline wetlands have been used as analogues for constructed wetlands in the oil sands (Trites and Bayley 2009, Raab and Bayley 2013, Phillips et al 2015). Natural wetlands had electrical conductivity from 0.5 to 28 dS/m and salinity was an important factor in determining plant community composition. Plant species richness decreased with increasing electrical conductivity. Trites and Bayley (2009) found most sites dominated by sodium chloride and sodium sulfate. Under flood and saline (20 to 30 ppt) conditions, few species could maintain adequate transpiration rates for peatland function (Phillips et al 2015). These species included northern reed grass, foxtail barley and wire rush; seaside arrow grass was tolerant.

5.5. Effects On Agricultural Crops

In Alberta the primary crops are canola, alfalfa, wheat, barley and hay with secondary crops of corn fodder, oats, rye, flaxseed, mixed grains, field peas, mustard seed, sugar beets and lentils, (Alberta Government 2014c). Most of these crops are considered non salt tolerant species or glycophytes (Eynard et al 2005). Some factors affecting crop and forage salt tolerance include variety or cultivar (Eynard et al 2005), irrigation (McKenzie 1988, Steppuhn 2013b), climate (Fowler and Hamm 1980, Maas 1993), developmental stage (Fowler and Hamm 1980, Maas 1993, Eynard et al 2005) and time of salt stress (Francois et al 1994).

Canada's Salinity Tolerance Testing Facility in Swift Current Saskatchewan has developed salt tolerances for wheat, barley, alfalfa, quinoa and perennial forage grasses. In solutions of sodium chloride and calcium chloride, electrical conductivity as low as 0.5 to 2.5 dS/m negatively affected number of fertile spikelets in five varieties (Katepwa, Neepawa, Biggar, Fielder, Kyle) of spring wheat and therefore grain yield (Steppuhn et al 1996, Steppuhn and Wall 1997). Grain production dropped to 90 % of the control at 4 dS/m. Durum wheat (Kyle), canola (Cyclone), green (Radley) and yellow (Carneval) field peas and pinto beans (Othello) performance was compared in sodium chloride and calcium chloride solution with electrical conductivities of 1.2, 11.2 and 24.9 dS/m (Steppuhn et al 2001). Only canola produced noticeable biomass at the highest electrical conductivity (20 % of control). Under moderate saline condition, all crops had 50 % or greater decline in biomass and grain yield. Emergence and survival were not affected at this salinity. Based on multiple plant response measures, canola was concluded to be the most salt tolerant followed by durum wheat, green field pea, then yellow field pea and pinto bean.

Alfalfa had reduced shoot biomass at 1.5 dS/m (Steppuhn et al 2012). Decreases in biomass declined with subsequent harvests, as salts (mix of sodium chloride, calcium chloride, sodium sulfate, magnesium sulfate) were likely removed from soil. Of nine cultivars, C7 produced the most biomass at 1.5 dS/m and Halo at 8 dS/m, similar to C7. Alfalfa cultivars, accessions and populations differed in salt tolerance at germination (Mohammed et al 1989). Germination, leaf number, lateral root number and seedling height decreased for all populations with increasing salt; germination significantly decreased when sodium chloride exceeded 220 mM. Height and yield of six alfalfa varieties irrigated with saline water decreased (Brown and Hayward 1956).

Barley is one of the most salt tolerant cereal crops. Cultivated barley (Harrington) was more negatively affected by sulfate salinity than wild barley (Huang and Redmann 1995). Reduction in tiller number, leaf number, shoot height, root length and dry biomass occurred after 20 days in salt treatment. Salt stress resulted in thicker roots with larger vessels in cultivated barley. Under sulfate saline conditions (mix of magnesium sulfate, sodium sulfate and calcium chloride), wild barley accumulated less sodium in its leaves than cultivated barley did (Harrington) by compartmentalizing the sodium in its roots (Suhayda et al 1992). Wild barley had a better sodium-potassium ratio and higher root to shoot sulfate. Calcium addition greatly improved conditions for cultivated barley but not for wild barley in both studies. In the field, McKenzie et al (1983) found a 50 % reduction in barley (Klages and Galt) yield at electrical conductivity 7.8 dS/m. Soil sodium content, sodium adsorption ratio and electrical conductivity were strongly correlated with barley yield.

Over a gradient of saline conditions in the black soil zone of Saskatchewan, crop emergence (spring and fall wheat, spring and fall rye, barley, oats, rapeseed, flax) was delayed in saline soil for all species except rapeseed (Fowler and Hamm 1980). Seed yield, plant dry weight and height were first affected by saline conditions followed by kernel weight, date of maturity, protein and oil contents. Electrical conductivity at which mortality occurred was 10.8 to 11.9 dS/m for all cultivars except barley (Bonanza) and oats (Garry), which were at 15.6 dS/m. While barley and oats were most salt tolerant, barley was sensitive to salinity when based on declines in seed yield. Winter hardiness of winter wheat and winter rye was reduced by saline conditions. Spring wheat and rye were most affected following hot dry summer weather. Thus, there is a need to manage for cumulative effects on saline soils (salinity, heat, cold, drought). For seed oil crops, reduction in oil content was not observed until soil electrical conductivity was 8 to 9 dS/m.

Munn and Stewart (1989) studied tolerance of four crops to oil well brine (electrical conductivity 124 to 145 dS/m, sodium 14,800 to 15,800 mg/L, chloride 55,000 to 57,000 mg/L, boron 9 to 11 mg/L). Germination was most reduced for soybeans (Sparks) and tall fescue (Chesapeake), with increasing volume of brine in irrigation water from 1 to 10 % resulting in greater reductions. Brine concentrations had little effect on germination of winter wheat (Hillsdale) and garden peas (Little Marvel); 100 % brine solution resulted in no crop seed germinating. With increasing brine from 0 to 10 %, tall fescue plumule length was reduced by 91 %, in garden peas by 60 % and wheat by 36 %. A 10 % brine solution reduced soybean dry weight biomass by 33 %.

A new crop of interest as a food oil, livestock feed and biofuel source is camelina. Camelina’s (CS15) ability to establish and grow under saline conditions was compared to canola (InVigor 9590) in sulfate solutions (mix of sodium chloride, magnesium sulfate, sodium sulfate) with electrical conductivities of 1.4, 3, 6, 10, 15, 20 and 28 dS/m (Steppuhn et al 2010). Negative effects on camelina emergence, survival and seed oil content occurred beyond 10 dS/m and effects on height beyond 6 dS/m. Canola maintained emergence and survival until 28 dS/m and seed oil content up to 20 dS/m. Grain yield for both crops was negatively affected at lower electrical conductivities than other measures.

5.6. Effects On Forages

Of 12 forage grass cultivars tested for salinity tolerance, tall wheat grass (Orbit) had highest emergence in sodium chloride solution with electrical conductivity 15 dS/m, at greater than 90 %. At 20 dS/m, emergence was 75 % (Acharya et al 1992). Orbit is a Canadian cultivar and recommended for saline areas in southern Alberta (Alberta Forage Variety Committee 1990). Of 12 cultivars tested only two other species had emergence greater than 50 % at electrical conductivity 15 dS/m, russian wild rye (Cabree) (65 %) and northern wheat grass (Elbee) (56 %). Seven species had emergence of 40 to 50 %, with slender wheat grass (Revenue) and Kentucky blue grass (Nugget), having lowest emergence at 33 % and 32 %, respectively.

Salt tolerance is species and population specific as plants are influenced by local site and climate conditions. In 1441 accessions of alpine blue grass and 406 accessions of slender wheat grass, very few were as salt tolerant as the reference species tall wheat grass (Orbit) in a sodium chloride solution with electrical conductivity 15 dS/m (Acharya et al 1992). More than 75 % of slender wheat grass ecotypes had less than 40 % of the reference species emergence and two thirds of the alpine blue grass ecotypes had less than 60 %. Pearen et al (1997) selected best performing lines from Acharya et al (1992) and exposed them to sodium chloride solutions with electrical conductivities of 2, 7, 15 and 23 dS/m. High emergence under saline conditions was not associated with salt tolerance during late development stages. Root biomass was reduced 11 to 87 % and shoot biomass 65 to 98 % over the range of electrical conductivities depending on accession line. Of common slender wheat grass cultivars used in reclamation, Adanac was more sensitive to salinity than Revenue based on root and shoot biomass.

Common forages, crested wheat grass (Nordan), russian wild rye (Vinall) and western wheat grass (Flintlock) receiving a sodium chloride and calcium chloride solution at four rates (0, 4, 8 and 16 dS/m electrical conductivity, greater than 3 sodium adsorption ratio) had delayed and reduced emergence at the two higher rates (Mueller and Bowman 1989). The study examined effect of soil water content (field capacity, moderately dry, dry) at the same salinity levels, however, due to high variation in evapotranspiration rates between treatments, salinity was not a significant factor and data were pooled. Western wheat grass (Walsh) tolerated and produced two to four times the shoot biomass of four other forage grasses in heavy clay saline soils (electrical conductivity 9 to 21 dS/m) near Stirling Alberta (Smoliak and Johnston 1983).

Salt tolerance values are not absolute and are affected by soil salt concentrations and land management (McKenzie 1988, McKenzie and Najda 1994). Irrigation prior to seeding can reduce salts in surface soil and improve germination, a stage of development particularly sensitive to salinity. In irrigated high salinity zones (7.8 to 10.0 dS/m) near Millicent Alberta, russian wild rye (Swift), tall wheat grass (Orbit), smooth brome (Carlton), crested wheat grass (Fairway), meadow brome (Regar) and altai wild rye (Prairieland) had high yield and were long lived (McKenzie and Najda 1994). In non irrigated high salinity zones (electrical conductivity 12.2 to 15.2 dS/m) near Sheerness Alberta, dahurian wild rye (Arthur), tall wheat grass and crested wheat grass had highest yields. Timothy (Climax) and redtop (Reton) were not tolerant of high salinity but performed well in moderately saline areas (3 to 9 dS/m). Altai wild rye, dahurian wild rye, tall wheat grass, russian wild rye and slender wheat grass tolerated maximum electrical conductivity of 16 dS/m (McKenzie 1988). In other studies, slender wheat grass

(Revenue) was less tolerant of saline conditions in the long term (McKenzie and Najda 1994). While turf grasses did not perform as well as forages, there was a difference in their salt tolerance (McKenzie and Najda 1994). Tall fescue (Courtenay) and creeping red fescue (Boreal) were tolerant of moderately saline sites (electrical conductivity 3 to 9 dS/m) while sheep fescue (Nakiska) and kentucky blue grass (Troy) were salt sensitive.

Smooth brome was most tolerant of salt and hydrocarbon contamination in three aged flare pit soils with electrical conductivity 3 to 5.2 dS/m (Rutherford et al 2005). Alfalfa was most sensitive to saline conditions but tolerant of hydrocarbons. The most saline soil resulted in lowest seedling emergence for most forages but some of the highest shoot biomass.

Development of cultivars tolerant of saline conditions is a priority for agriculture in western Canada. Two new cultivars are NewHy, a cross between quack grass and blue bunch wheat grass, and Strain A6 green wheat grass (Steppuhn and Asay 2005). NewHy maintained survival of more than 80 % over 70 days at electrical conductivity 24 dS/m in a chloride salinized media, while green wheat grass achieved this at electrical conductivity 12 dS/m. In sulfate salinized media, two wheat grass cultivars achieved 75 % or greater survival over 80 days at electrical conductivity 38 dS/m and are considered as salt tolerant as the standard, Orbit tall wheat grass.

Native populations and cultivars of june grass were compared to other cool season forage cultivars to determine salt tolerance (Wang et al 2011). Each population or cultivar was exposed to sodium chloride with electrical conductivities 0, 8.8, 15.3, 20.4 and 25.7 dS/m in the first study. When species were pooled, there was a significant decline in germination with each increase in electrical conductivity, from 100 % at electrical conductivity 0, to less than 5 % germination at 20 dS/m. The experiment was repeated with a narrower range of electrical conductivities (1.3, 6.5, 10.7, 14.8, 18.5 dS/m) as greater than 15 was detrimental to germination, shoot biomass, electrolyte leakage and visual quality. Results of the second experiment agreed. In both experiments, june grass performance under saline conditions was similar among cultivar and native populations, and similar to that of sheep (67135) and hard (MN-HD1) fescues and kentucky blue grass (Park). Relative salt tolerance was dependent on plant measure and development stage.

5.7. Effects On Native Vegetation

5.7.1. Non woody species

Species that naturally tolerate higher salt concentrations, halophytes, are often considered weeds (Braidek et al 1984, Redmann and Fedec 1987). A large number of halophytes are in the Chenopodiaceae family (more than 50% of the species) including kochia, russian thistle and goosefoot species (Glenn et al 1999). Poaceae, Fabaceae and Asteraceae contain a high proportion of the world’s halophytes, however, less than 5 % of species in each family are halophytes. Most native plant species are not halophytes and are negatively affected by saline or sodic soils. High salinity in soils is often associated with low vegetation cover and high bare ground (Srivastava and Jefferies 1995, Caine et al 2000) and result in changes in plant community composition (Burchill and Kenkel 1991). Brine spills often result in complete vegetation kill whether immediately or within a few years (Rowell and Crepin 1977, Innes and

Webster 1981, Walters and Auchmoody 1989, Leskiw et al 2012, White 2012). A small percentage of brines contain hydrocarbons and studies have shown salinity is a greater factor (Keyes and Mott 1999, Colgan et al. 2002).

Ten years following a well blowout in north eastern British Columbia, native vegetation re-established (Leskiw et al 2012). Dominant cover in least impacted plots (electrical conductivity less than 0.4 except C horizon, ~1.0; sodium adsorption ratio less than 5) progressed from herbaceous to shrubs to mosses following succession similar to that after fire or clear cutting. As salts leach from the upper soil profile, shallow rooted, not salt tolerant, mosses recover. In high impacted plots (electrical conductivity 0.4 to 0.6 in LFH and A horizon, 1.0 to 1.8 in B and C horizons; sodium adsorption ratio 1 in LFH, 8 in A horizon, 15 in B and C horizons), however, moss cover did not change much over 10 years and dominant species between least and most impacted plots varied. Species diversity indices, based on rare and dominant species, increased with time. Sodium and chloride concentrations in soil were above provincial guidelines at the beginning of the study but below guidelines within two years.

Brine applied to forest soil at 1.52 kg/m^2 of chloride reduced understory red maple and flowering dogwood 30 to 40 %, and some herbaceous species were eliminated (DeWalle and Galeone 1990). Overstory trees were not affected. Vegetation re-established on a brine spill in north west Pennsylvania (Walters and Auchmoody 1989). Brine contained sodium chloride and calcium chloride with concentrations of sodium and chloride exceeding 20,000 and 50,000 mg/L, respectively. Within two years, salts were at predisturbance levels, likely due to rapid leaching from surface soil. Vegetation (7 to 11 % cover) established in the first year including tree seedlings; in 4 years seedling density and composition were similar to predisturbance.

On a brine contaminated drilling site in western North Dakota, there was less than 2 % vegetation cover with salt grass being dominant (Halvorson and Lang 1989). Electrical conductivity was 64 dS/m and sodium adsorption ratio 106. Two years later with no reclamation, electrical conductivity and sodium adsorption ratio were 30 dS/m and 70, respectively. A few other species established including native species, such as western wheat grass, prairie sagewort and plains prickly pear cactus, and non native weeds, including pepper grass and blue bur; cover was still less than 10 % and bare ground had increased from 25 to 43 %. Sodium and chloride decreased from 682 and 811 meq/L to 287 and 314 meq/L, respectively.

An experimental brine spill (sodium chloride 13,100 mg/L, electrical conductivity 60 dS/m) in boreal Alberta resulted in immediate necrosis in most species with some species having a higher proportion of damaged vegetation than healthy vegetation (Innes and Webster 1981). There were two sites, a lodgepole pine – white spruce forest (site 1) and a more mesic lodgepole pine – black spruce forest (site 2). Without reclamation, signs of vegetation damage increased throughout the first growing season at both sites. At site 1, balsam fir, low bush cranberry, bunch berry, pink wintergreen and twin flower were particularly sensitive to increased salinity and seedlings had severe damage (78 to 100 % of total cover) within the first year. By the second year, most species, except balsam fir, recovered. Forest feather moss had high damage in the second year (60 %), with less damage in both years for knights' plume. Some native species appeared tolerant to saline conditions and naturally invaded, including red raspberry, cranesbill, scurf pea and foxtail barley. At site 2, black spruce and low shrubs, including bog cranberry, blueberry and labrador tea, had greater than 90 % severe damage along with herbaceous species, twin flower and sweet colts foot, and mosses, hair cap moss and big red stem. In the second year, visual damage remained high (greater than 75 %) for black spruce, labrador tea and bog cranberry.

Inland salt grass is a salt tolerant native species appropriate for revegetation of disturbed sites in prairie regions. Aschenbach (2006) found western wheat grass as salt tolerant as inland salt grass at electrical conductivity up to 57.7 dS/m. At electrical conductivity 17.9 dS/m, inland salt grass relative growth rate was reduced by 10 % and western wheat grass by 38 %. There were no differences in results for western wheat grass, but there were for inland salt grass. Desserud et al (2015) found prostrate amaranth cover on reclaimed well sites was significantly negatively correlated with electrical conductivity (0.7 to 2.8 dS/m) but two common weed species were not.

Salt is commonly applied to roads in Canada during the winter as sodium chloride and calcium chloride. Negative effects of road salt on adjacent vegetation are well documented (Wilcox 1984, 1986, Wilcox and Andrus 1987, Eaton et al 1999, Viskari and Karenlampi 1999, Caine et al 2000, Pederson et al 2000, Baltrenas et al 2006, Gibson and Carrington 2002). Caine et al (2000) conducted a quotient based assessment of road salt impacts on vegetation in Canada and concluded that threshold values (based on 25 % effect level, no observed or lowest effect level) for roots from 215 to 300 mg/L sodium and 300 mg/L chloride and for tissue exposure, from 575 to 650 mg/L sodium and 800 to 1650 mg/L chloride.

Howat (2000) provided salt tolerance ranges for many native boreal species, however, ranges were based on few scientific studies and tolerance defined as at least one document indicating plant survival, and possibly growth, occurred during the experiment. Specific conditions and what percent of plants survived were not provided.

Applied manure and composts can be sources of salinity and phytotoxic to plants (Naeth et al 2003). In a review of use of municipal solid waste composts in agriculture, Hargreaves et al (2008) concluded that its application increased electrical conductivity in unamended agricultural soil from 0 to 4 dS/m to 3.7 to 7.5 dS/m with electrical conductivity decreasing with time. The higher electrical conductivity was potentially detrimental to seed germination but plant growth was only inhibited in some studies. Significant increases in foliar sodium concentrations were reported in most studies. Horticultural woody species grown in a municipal solid waste compost medium showed half were tolerant of increasing electrical conductivity with increased rate of application (Chong 2000). Application of fresh or composted cattle manure to an agriculture field increased soil electrical conductivity, sodium, chloride and sodium adsorption ratio but barley yields were still significantly greatly than in unamended soil (Miller et al 2004, 2005). Electrical conductivity remained less than 1 dS/m, sodium adsorption ratio less than 4, sodium less than 0.5 Mg/ha and chloride less than 0.3 Mg/ha in the rooting zone.

5.7.2. Woody species

Most of the research on salt tolerance of woody species has been conducted in boreal Alberta with a focus on four key species (jack pine, white spruce, black spruce, red osier dogwood). Renault et al (1998) suggest that coniferous species are less affected by salt contaminated composite tailings water than deciduous species such as red osier dogwood and aspen, although there was much higher variability within conifers than deciduous species.

Specific salt tolerances have not been determined for jack pine. At 60 mM there was extensive needle necrosis and reduced growth, dry weights, number of new shoots and roots, survival, net photosynthesis, transpiration rates, root respiration and carotenoid content (Apostol et al 2002, 2004, Franklin et al 2002a, Franklin and Zwiazek 2004). Increasing salt had a detrimental effect (Croser et al 2001). Even at 25 mM sodium chloride, needle necrosis occurred and root dry weight, photosynthesis and transpiration rates were reduced (Nguyen et al 2006). Germination was not affected by sodium chloride up to 50 mM (Croser et al 2001). Elevated concentrations of potassium, magnesium, manganese, nitrogen and phosphorus in shoots under sodium chloride stress suggest nutrient deficiency is not a concern. Jack pine retained sodium and chloride in roots and shoots, and concentrates chloride in shoots, resulting in extensive needle necrosis and electrolyte leakage. Chloride appears to accelerate root to shoot transport of sodium, and may do so by altering cell membrane permeability, thereby increasing leaf tissue concentrations relative to sulfate salts (Franklin and Zwiazek 2004). Negative effects of salt on jack pine are exacerbated in the presence of other contaminants such as boron (Apostol et al 2002), naphthenic acids (Apostol et al 2004) and under hypoxia (Apostol and Zwiazek 2004).

Black spruce under salt stress had significant needle necrosis, electrolyte leakage, reduced seed germination, root dry weight and net photosynthesis and transpiration rates (Hocking and Massey 1972, Renault et al 1998, Croser et al 2001, Redfield and Zwiazek 2002, Nguyen et al 2006). Increasing sodium chloride resulted in increased negative affects with the exception of water potential and stomatal conductance (Redfield and Zwiazek 2002). Black spruce appears to be tolerant of sodium chloride concentrations up to 20 mM, but less tolerant of sodium sulfate (Croser et al 2001) and perhaps even less tolerant of $MgSO_4$ (Hocking and Massey 1972). Black spruce is more salt sensitive than jack pine or white spruce.

White spruce under salt stress had leaf tip necrosis, reduced seed germination, shoot and root lengths, number of lateral roots and shoot fresh weight (Hocking and Massey 1972, Renault et al 1998, Croser et al 2001, Nguyen et al 2006, Duan et al 2015). Salt sensitivity was apparent at 10 to 20 mM sodium chloride or sodium sulfate (Croser et al 2001). Salinity as measured by high electrical conductivity and decreased foliar potassium limited white spruce growth on reclaimed overburden sites (Duan et al 2015).

Red osier dogwood is considered salt tolerant relative to other boreal woody plants (Renault et al 1998, 1999, 2001, Redfield et al 2003, Purdy et al 2005, Renault 2012). Red osier dogwood tolerates salinity up to 50 mM sodium chloride by limiting sodium transport from roots to shoots, and it tolerates drought by increasing proline production in leaf tissue (Renault 2012). Dogwood survival in consolidated tailings and water treatments was significantly less than controls; electrical conductivity in the control was 1.4 dS/m and increased in treatments between 4.4 to 7.7 dS/m (Redfield et al 2003).

While storage of salt ions in the roots can be a tolerance mechanism in long lived woody species, raspberry plants did not exhibit this trait (Redfield et al 2004). Raspberry plants accumulated sodium and chloride in shoots, along with sulfur and boron, and had increased electrolyte leakage under salt stress caused by composite tailings water (electrical conductivity 2.2 dS/m). Renault et al (1998) reported low to no survival of raspberry on composite tailings water sites with electrical conductivity greater than 1.5 dS/m. Strawberry had reduced survival at sites with an electrical conductivity greater than 2.0 dS/m. As electrical conductivity increased, electrolyte leakage and water potential significantly increased and transpiration decreased. Buffalo berry was tolerant of sodium chloride and sodium sulfate salinity (Renault et al 1999).

Lodgepole pine and white spruce germination was reduced in sandy soil with sodium sulfate salinity and electrical conductivity of 2.7 dS/m, but in clay soil could tolerate up to 4.7 dS/m. Magnesium chloride considerably reduced germination and biomass in both soils (Hocking and Massey 1972). Trembling aspen root and shoot dry weights were not affected by 25 mM sodium chloride after 6 weeks (Yi et al 2008). Hybrid poplar was salt tolerant (Renault et al 1998, 1999).

Siberian larch growth declined as electrical conductivity approached 4 dS/m under sulfate saline conditions in the field (Carter 1980). Dieback may occur at this electrical conductivity if at depth. This threshold for soil electrical conductivity would be lower under severe water stress. In the laboratory, under sulfate saline conditions, siberian larch growth began to decline between 2.0 and 5.3 dS/m and under chloride saline conditions in the laboratory, the electrical conductivity threshold was between 1.4 and 3.6 dS/m, where seedlings showed signs of top growth decline, necrosis and overall reduced survival.

5.7.3. Aquatic and non vascular species

A 2008 literature review of toxicity of salt ions to peatland flora, for development of risk based salinity guidelines, concluded there was little scientific research on wetland species and their salt tolerance, and results for agronomic or terrestrial species would not be applicable due to distinct differences in hydrologic and soil properties and salt movement in wetlands (UMA Engineering 2007). The review included one American study on a peatland bryophyte, where sodium chloride salt deposition on recurved sphagnum resulted in morality at all concentrations (Wilcox 1984). When grown in sodium chloride solutions, concentrations of 300 and 500 mg/L reduced growth and biomass, with chloride more detrimental to growth than sodium. Needs were identified for salt ion tolerance thresholds for major fen and bog bryophyte and vascular plant species to better understand the relationship between establishment of bryophytes and vascular plants in fens and bogs and depth to major zone of salt contamination.

Since this review, there have been several studies on salt tolerance of wetlands plant species (Crowe et al 2001, 2002, AECOM 2011, Koropchak and Vitt 2013, Mollard et al 2012, 2013, 2015, Glaeser et al 2016, Roy et al 2014, 2016). Cattails and sedges were the dominant vegetation in consolidated tailings wetlands with elevated electrical conductivity (2.2 dS/m), sodium (57 mg/L) and sulfate (710 (water) and 2600 (sediment) mg/L) (Crowe 1999, Crowe et al 2002). They spontaneously colonized saline wetlands with an electrical conductivity 3.1 dS/m and sodium concentration 622 mg/L (Mollard et al 2015). While these species can survive in saline conditions, physiological effects have been reported. In consolidated tailings wetlands with higher sodium concentrations (up to 465 mg/L), while there was no effect on cattail photosynthesis, altered levels of the protein dehydrin suggest plants were under osmotic stress and in the long term this may affect survival (Crowe et al 2001). Mollard et al (2013) found photosynthesis in cattails is not affected in consolidated tailings wetlands, but plants had fewer and smaller leaves and lower biomass relative to natural wetlands. In a study of specific effects of sodium on cattails, Koropchak and Vitt (2013) reported they were tolerant up to 300 mg/L sodium, while at 600 mg/L health, height and biomass decreased substantially. Water sedge, while considered salt tolerant, was smaller at electrical conductivity 3.4 dS/m (Mollard et al

2012) and had less root biomass (Roy et al 2014) in oil sands wetlands. Germination of reed canary grass was reduced by salinity (Crowe et al 2001).

Only one study investigated salt tolerance of wetland forbs (Mollard et al 2015). The three species had 100 % survival following the first growing season although there were many physiological effects. Mint had high concentrations of sodium in leaves, lower stomatal conductance which negatively affected transpiration and were shorter. Smartweed had significantly higher sodium in leaves and reduced photochemistry. Skull cap had a lower net carbon dioxide assimilation rate.

Ross et al (1984) found species affected moss response to salt contamination significantly. Different volumes and exposure times of brine (electrical conductivity 67.7 dS/m, sodium adsorption ratio 92.4, sodium 14,457 mg/L, chloride 2,030 mg/L, sulfate 634 mg/L) were applied to three moss species and regrowth biomass was assessed over 30 weeks. Species were feather moss, knights' plume and big red stem. The greatest declines in biomass for all three occurred between electrical conductivity 0 and 20 dS/m, with little difference between 40 and 60 dS/m. Mosses were more drought tolerant than salt tolerant; feather moss was most salt sensitive. Increased exposure time resulted in reduced regrowth biomass for some species. Innes and Webster (1981) found common hair cap, big red stem and knights' plume moderately tolerant of brine solutions with electrical conductivities from 0.002 to 19.6 dS/m. Regrowth steadily declined in this range and then considerably dropped off between 19.6 and 31.1 dS/m.

5.8. Factors Influencing Salt Impact

5.8.1. Salt type

Global accumulation of soluble salts, specifically sodium chloride, sodium carbonate and calcium chloride are responsible for significant loss of agricultural productivity (Nawaz et al 2010). Most research on salt stress in plants focuses on sodium and chloride. In certain regions of the world, such as the Canadian prairies, sulfate salts are dominant in salt affected lands (Chang et al 1983, Curtain et al 1993). Sodium is the dominant cation in salt affected soils in the Canadian prairies; magnesium is common (Dodd et al 1964, Redman and Fedec 1987). In the boreal forest region, high concentrations of sodium, chloride and sulfate have been reported in natural saline communities (Purdy et al 2005, Close et al 2007, Trites and Bayley 2009, Lilles et al 2011). Specific ions of these salts and their relative concentrations can have significant effects on plant salt tolerance and toxicity.

Current guidelines for remediation of saline soils in Alberta are based on sodium chloride. While the predominant salt in well site process water is sodium chloride, soil contamination due to sodium sulfate can occur on sulfur storage sites following sour gas operations and in oil sands process water. Road salt contamination is mainly sodium chloride and calcium chloride (Caine et al 2000). Thus there is growing interest in understanding the difference in effects, if any, of these salts and ions on vegetation. In particular the potentially different effects of chloride and sulfate salts, as some indicate plants are less sensitive to sulfate than chloride (Howat 2000).

In a literature review by Millennium Environmental Management Solutions (2013) on relative effects of sodium chloride and sodium sulfate on vegetation, sodium chloride was concluded to be more toxic to plants than sodium sulfate. Of fourteen studies reviewed, nine supported this conclusion; two found it to be less toxic; and the remaining were inconclusive. Six of the studies experimentally compared effects of the two salts on native woody boreal species; both salts negatively affected plants, although the relative impact was dependent on the measure of injury. Needle necrosis and electrolyte leakage were consistently greater with sodium chloride than sodium sulfate salinity and with increasing concentration (Carter 1980, Franklin et al 2002b, Redfield and Zwiazek 2002, Franklin and Zwiazek 2004, Nguyen et al 2006). Needle necrosis may be a result of greater sodium ion concentrations in leaf tissue with sodium chloride salinity relative to sodium sulfate, rather than changes in chloride concentrations (Renault et al 2001, Franklin et al 2002b). At turgor point, greater negative osmotic potential was found with sodium sulfate, which may reduce electrolyte leakage (Redfield and Zwaizek 2002). In a deciduous species, root and shoot dry weights decreased more with sodium sulfate, although transpiration was similarly reduced by both sodium chloride and sodium sulfate (Renault et al 2001).

The Canadian Salt Tolerance Testing Facility conducted research on effects of salts on common crops and found chloride salts to be most phytotoxic. Wheat, barley, tall wheat grass and green wheat grass were more tolerant of calcium sulfate solution than a mix of sodium chloride and calcium chloride (Steppuhn et al 2014). In a similar study, with two canola cultivars, sulfate saline solution with electrical conductivity 1.6 to 26 dS/m had little effect on emergence and survival except at the highest electrical conductivity (Steppuhn and Raney 2005). However, a mix of sodium chloride and calcium chloride solution with electrical conductivity 1.4 to 32 dS/m considerably reduced emergence and survival of the same canola cultivars at electrical conductivity 22 or 32 dS/m. There was no difference between 1.4 and 14 dS/m concentrations. In a separate experiment to determine effect of chloride and sulfate solutions on above ground biomass and height, biomass was greater for barley and two canola cultivars and height for one canola cultivar in sulfate than in chloride treatments. Type of salt also impacts forages. At the same electrical conductivity (15 dS/m), emergence of slender wheat grass was inhibited most by sodium chloride (58 %), and least inhibited by magnesium sulfate (85 %), followed or sodium sulfate (81 %), then a mixture of the three salts (68 %) (Acharya et al 1992).

Not all studies report differences in visible measures of plant stress such as reduced establishment, growth or health under different types of salt stress. Croser et al (2001) found no difference in impact between sodium chloride and sodium sulfate as measured by jack pine, white spruce and black spruce germination, emergence and early growth. Salt type also had no effect on boreal mosses (Pouliot et al 2013).

Type of salt directly affects plant physiological response to salinity. Bie et al (2004) reported very different mechanisms of plant toxicity with sodium sulfate and sodium carbonate. Reduction in lettuce growth occurred with both salts; with sodium sulfate this was due to osmotic stress and excessive accumulation of sodium, and with sodium carbonate it was due to bicarbonate toxicity and high pH. In peanuts, sodium chloride had a greater effect on chlorophyll content and sodium sulfate had a greater effect on rate of photosynthetic carbon dioxide fixation (Chavan and Karadge 1980). Sodium chloride was more detrimental than sodium sulfate on translocation of photosynthetic assimilates in beans (Bhivare and Chavan 1987). Barley growth was greater under sodium sulfate stress than sodium chloride, however, plants were severely calcium deficient (Curtain et al 1993). Kochia, a salt tolerant plant efficient in synthesizing calcium, did not have this deficiency under the same treatments. The main mechanisms of sulfate salt injury are calcium deficiency (Janzen and Chang 1987, Suhayda et al 1992) and osmotic stress (Meiri et al 1971, Redfield and Zwaizek 2002).

In a review by Greenway and Munns (1980) the relative effect of sodium versus chloride ions was concluded to be unknown. More recent research has shown that sodium is likely the main ion responsible for phytotoxicity, although the magnitude of the effect is dependent on other ions. While investigating impacts of barium contamination from brine spills on vegetation, Cipollini and Pickering (1986) found sodium was the cause of most vegetation damage as it disrupted the sodium to potassium ratio, which was directly correlated with changes in corn and rye grass yields. Where sodium was 2400 mg/L, with sodium to potassium ratio 50, there was no vegetation. Renault et al (2001) found positive relationships between sodium accumulation in plant tissue and plant response measures. With increasing concentrations of either sodium chloride or sodium sulfate, red osier dogwood stomatal conductance, photosynthetic rate and dry weights were reduced and sodium concentration in leaf tissue increased. Even low sodium concentrations can cause needle necrosis, as in the presence of chloride, plants increase uptake and translocation of sodium (Franklin et al 2002, Franklin and Zwiazek 2004). Chloride is thought to increase membrane permeability and reduce plant ability to compartmentalize ions and is an important factor in conifer salt injury, not just sodium.

The relative importance of specific ion versus osmotic effects on plant growth may be dependent on salt type. El-Samad and Shaddad (2008) found sodium carbonate was more toxic to pea plants than sodium chloride or sodium sulfate. Plants under sodium chloride salt stress significantly accumulated organic solutes at all osmotic potentials, however those under sodium sulfate stress only did so at high osmotic potential. These solutes are precursers for osmotic adjustments and may improve water tissue content, which is generally low for plant survival in saline conditions, at low to moderate salinity levels. These osmotic adjustments resulted in greater fresh and dry biomass under sodium sulfate stress. While plants under both types of salt stress had high concentrations of chloride or sulfate ions, respectively, chloride ions have a greater rate of adsorption and may therefore contribute to osmotic adjustments more than sulfate. Egan et al (1997) report that the phytotoxicity of saline solutions on seed germination and early growth were a result of osmotic, not specific ion effects of either chloride or sulfate.

5.8.2. Soil type

Few studies directly investigated impact of soil type and texture on plant response to salinity, although it is assumed that if salt accumulation and movement is dependent on soil properties, plant response will be also. In a review of crop response to salt affected soils, Eynard et al (2005) concluded the magnitude of crop yield reduction is dependent on soil type and management. Salinity changes significantly over short distances in the field (Fowler and Hamm 1980, Steppuhn 2013a). In a survey of soils across the Great Plains to assess salt effects on wheat across a range of soil types (sandy loam to clay texture), soluble salt content could not be more than 0.5 % for good yield and 0.4 % for high yields regardless of soil type. The nutrient balance of soil also affects plant response to salinity (Curtin et al 1993).

Plant response to salt contamination in two Alberta soil types was investigated, the first a fine grained clay loam from near Delacour and the second a coarse grained sandy loam from near

Vulcan (MEMS 2013). For barley, alfalfa and northern wheat grass, there were considerable differences between soils in chloride and sulfate concentrations at which a 25 % decrease in plant response was observed. Root and shoot length and biomass were greatly affected by chloride and sulphate concentrations. Plants generally tolerated higher concentrations of chloride and sulfate in fine than coarse soil with a few exceptions for root length and biomass. When salinity was expressed as electrical conductivity, the magnitude of differences was not as great and tolerance varied among species and soil types. Electrical conductivity and sulfate concentration tolerance values were higher in shoots than roots in sulfate saline conditions but variable for chloride saline conditions regardless of soil type.

A study comparing a contaminated heavy clay and sandy soils, found woody plants had better germination and survival in clay soil even though electrical conductivity was greater (Hocking and Massey 1972). This was evident when contaminated with sodium sulfate, magnesium chloride or a mixture of the two. The clay soil had high calcium content and calcium is often used to remediate saline soils. Both soils were low in nitrogen and phosphorus. In naturally saline boreal forest communities, differences in plant tolerance to saline conditions varied slightly across soil types (Close et al 2007, Lilles et al 2011). Soil water regime and salinity were greater factors determining plant composition. Liang et al (1995) found boron was the most important factor affecting barley growth in three brine contaminated soils (sand, clay, loam), even though concentrations of sodium and chloride were high.

5.8.3. Other factors

Most research on the impact of salts on plants has been conducted under controlled conditions in a laboratory or plant growth facility. In the field the influence of climate and site conditions may provide different results. Growth media in controlled studies included perilite, vermiculite, potting soil and sand. Variability in salt concentrations in the soil profile occurs spatially and temporally and is recognized as the main limiting factor to determining plant salt tolerance under field conditions (Fowler and Hamm 1980).

In a review of impacts of salinity on crops, the relative effect of salt stress on biomass and grain yield was dependent on cultivar and developmental stage at which salt stress occurred (Eynard et al 2005). Steppuhn and Wall (1997) found that applying salts after germination resulted in higher salt tolerance than if salts were added prior to seeding. Francois et al (1994) found wheat continuously exposed to salinity had significantly fewer kernels per spikelet and lower kernel mass; however, when exposed to salinity only in early development stages, there was no effect. While some advocate for greater long term research in the field (Howat 2000), others propose that field testing to develop salt tolerance criteria is impossible due to inherent natural variability of field conditions (Steppuhn and Wall 1997, 1999). Some studies focus on germination and early establishment (Mohammad et al 1989), as if plants cannot survive these stages, later effects of salinity are not relevant. Many plant species are most sensitive to salinity in early development stages. Colgan et al (2002) found tall fescue had no or low germination and high survival and biomass in sodium chloride and brine contaminated soil (electrical conductivity 16 dS/m), emphasizing that salt tolerance needs to be assessed throughout a plant lifecycle.

Species and seed provenance significantly affected boreal woody plant biomass and necrosis when plants were grown in solutions with sodium chloride concentrations 0 to 75 mM and composite tailings water (electrical conductivity 6170 uS/cm, sodium 1580, sulfate 2020, chloride 691 mg/L) (Khasa et al 2002). The researchers found that intraspecific variation may be more important that interspecific variation when assessing species salt tolerance with three key factors being latitude, longitude and elevation. Most species had 0 % survival in 50 or 75 mM sodium chloride treatments. Renault (2012) found that source of seed can have a great effect on species salt tolerance. Flowering dogwood seed sourced from three provinces varied in growth, development and adaptive mechanisms to salinity.

Interaction between pH and salinity may be present for some plant species. Higher tissue concentrations of sodium and chloride and greater mortality occurred in rat root at pH 8.5 than pH 7.0 (Calvo-Polanco et al 2014). At pH 7.0 (tested 6 to 9.5) there was a significantly greater growth rate for the first four weeks but after this, pH had little effect on growth.

6. SALT AFFECTED SOIL REMEDIATION

6.1. Salt Affected Soil Remediation Decisions

Remediation options for salt affected soils are mainly based on site and spill characteristics and on the amount of risk associated with the potential movement of salts and adverse effects on receptors. Factors to be considered include total mass of salts present, volume of contaminated soil, depth to ground water, permeability of subsoil, potential to cause saline seep and other potential receptors nearby (Alberta Environment 2001). For spills, initial response can significantly facilitate remediation and reclamation (Alberta Environment 2001). Detailed response procedures are available, such as those from the Petroleum Institute Training Service. Remediation options may be in situ or ex situ and on or off site.

6.2. Natural Attenuation Through Salt Movement

An important factor in reclamation and remediation of salt affected soils is the period of time required for salts introduced into the topsoil and upper subsoil root zone during disturbance to leach or move out of the root zone naturally. If the salt content of the reconstructed root zone decreases naturally to an acceptable range within an acceptable period of time, it may impact reclamation approaches. This process is known as natural attenuation. Finlayson (1993) conducted a literature review on movement of salts in disturbed soils and concluded that the body of available knowledge on movement of soluble salts through disturbed soils is meagre, with most published work on sodium chloride contamination. Most researchers cited agreed that soluble salt content of salinized disturbed soils decreases over time, although the length of time required for soils to return to pre-construction or undisturbed conditions varied widely.

In the brown soil zone, 5 years may be sufficient for electrical conductivity and sodium adsorption ratio to return to pre-disturbance conditions in coarse to moderately coarse soils (Finlayson 1993). In fine textured soils, more than 10 years may be required for electrical conductivity to return to pre-construction conditions, although sodium adsorption could return within 10 years. In the dark brown zone, 5 years was marginal for some soils to return to pre-construction conditions. Although Finlayson (1993) thought rates of salt movement through disturbed soils in the black soil zone were likely similar to or more rapid than in the dark brown soil zone, few data were available and results were considered inconclusive.

Finlayson (1993) found changes in salt concentration could occur after a single heavy precipitation event, or noted that salts increased in some years and decreased in others. However, no other studies were found which documented seasonal changes in salt distribution throughout disturbed soils. Upward movement of salts from strongly saline spoil material into non saline subsoil or topsoil was documented in mine reclamation studies. Upward salt movement could occur, but was not considered to be a problem since the necessary salt gradient between spoil and topsoil is less common in relatively shallow disturbances from pipeline and well site construction relative to mines.

Naeth (1985) and Naeth et al (1987) examined salt movement on parallel pipeline trenches of different ages that were constructed on loam to clay loam soils without topsoil salvage. In a 2 year old trench, electrical conductivity and sodium adsorption ratios were much higher than undisturbed prairie controls at most depths. In an adjacent 11 year old trench, both electrical conductivity and sodium adsorption ratio remained higher than the adjacent undisturbed control, but most differences were small to a depth of 60 cm. Most differences disappeared in a 26 year old trench. In a follow up 10 years after construction of the youngest pipeline, Naeth (1993) found electrical conductivity was lower in 1991 than in 1983 to a depth of 15 cm; electrical conductivity remained higher than controls at 15 to 45 cm depths. Sodium adsorption ratio returned to control conditions within the 10 year period.

In a study of a pipeline in moderately coarse to coarse textured soils, electrical conductivity in treatments with topsoil stripping were close to or lower than pre-construction levels after 3 years (Finlayson and Cannon 1993). The stripped topsoil never had elevated electrical conductivity, and initial increases in subsoil disappeared after 3 years. With no topsoil salvage, 3 years was not sufficient time for elevated electrical conductivity to return to pre-construction conditions in the upper 30 cm of reconstructed soil. Below 30 cm, initial increased electrical conductivity disappeared after 3 years with no topsoil stripping. After 3 years all initial differences in sodium adsorption ratio disappeared. After 4 and 5 years, no differences in electrical conductivity were found between deep plowed soils and adjacent conventionally tilled land, in sandy loam to sandy clay loam textured soils (Chang et al 1986).

De Jong and Button (1973) found trench electrical conductivity was higher than undisturbed controls in cultivated solonetzic sites 1 to 3 years after pipeline construction. On 8 to 11 year old pipelines there were no differences between trench and controls. They found pipeline construction improved soil physical properties on trenches in solonetzic areas, which would result in leaching of salts. Knapik et al (1990) found after 5 years, trench electrical conductivity remained higher than controls at some depths, with differences of 0.3 to 4.7 dS/m. All trench sodium adsorption values were equal to or lower than controls after 5 years. Leskiw (1989) found a significant linear decline in topsoil electrical conductivity and sodium adsorption ratio over a 5 year period, to less than half the original values before mining. In upper subsoil (15 to 35 cm), there were no changes over 5 years in electrical conductivity or sodium adsorption ratio.

Finlayson (1993) found results of deep plowing and deep ripping studies inconclusive. Ballantyne (1983) found small increases in electrical conductivity persisted after 5 years in deep plowed sites relative to undisturbed controls. Riddell et al (1988) and Wetter et al (1987) found no differences in sodium adsorption ratio between deep ripped and adjacent conventional tilled sites after 1 to 5 years. Buckland and Pawluk (1985) found that 4 and 5 years after deep plowing elevated electrical conductivity and sodium adsorption ratio values were not returned to control levels in topsoil. Harker et al (1977) found electrical conductivity after 7 years was higher in A and B horizons of deep plowed soils than in conventional tilled soils by 2.7 and 5 dS/m, respectively. They found that topsoil salinity decreased after a single heavy rainfall of 14 cm. McAndrew and Malhi (1990) found slightly increased electrical conductivity remained in 12 year old deep plowed soils relative to conventional till at greater than 60 cm. They found no increased electrical conductivity at sites deep plowed 11, 20 and 29 years previously. Sandoval et al (1972) found electrical conductivity for 0 to 15 cm and 15 to 30 cm depth increments increased initially after deep plowing, then decreased after 5 years.

After mine site reclamation, Graveland et al (1988) found no change in electrical conductivity over 5 years to 15 cm depth immediately above the soil-spoil interface, but found increased sodium adsorption ratio in subsoil depth treatments and some upward movement of sodium from spoil into soil. At reclaimed mines, sodium adsorption ratio decreased after 5 years were noted by Merrill et al (1983). Richardson and Farmer (1982) found sodium adsorption decreased over 7 years in the upper 30 cm. Dollhopf et al (1980) found little change in electrical conductivity or sodium adsorption ratio of the upper 35 cm of replaced soil materials over 2 years, although they increased gradually at 35 to 70 cm, just above the soil-spoil interface and decreased over time below 70 cm. They found no upward movement from a sandy clay loam to clay loam subsoil overlying sandy loam soil material within 2 years. Merrill et al (1980) found sodium adsorption ratio increased at 15 to 30 cm in reconstructed soils, where non sodic soil material had been replaced over sodic spoil materials. Barth and Martin (1984) found significant sodium migration 7 to 14 cm upward into non saline soil after 5 years.

6.3. Leaching

The typical treatment for saline soils is leaching. Leaching requires net transport of water and salts in a downward direction through the soil profile. Volume of water must be sufficient to carry salts through the root zone to the drain tile or below the depth where upward capillary movement might cause re-salinization of surface soil. This requires the volume of water to be more than that which is evaporated, taken up by vegetation and stored in the soil.

In some cases, precipitation may be sufficient to wash salts from the soil. Snow fencing, straw bales and standing stubble help trap snow for additional water. In other cases, irrigation may be required. Leaching requirement is the calculated depth of water that must be passed through the plant root zone to maintain the electrical conductivity or sodium adsorption ratio at or below a specified value (Bresler et al 1982). Leaching fraction is the proportion of water that must be applied for a given time period to meet the leaching requirement. Adding water can increase the risk of salt movement into ground water or other receptors. In many jurisdictions, if leachate release has potential to cause further damage to living organisms or previously uncontaminated media, it must be collected and properly discarded (Alberta Environment 2001). Soil can be excavated and washed in ex situ salt removal treatment (Sastre-Conde et al 2105).

Leaching water is usually applied by sprinkler or by continuous or intermittent ponding using dikes or berms. Intermittent application of leaching water with drainage between applications can to be more efficient in remediation of soil salinity than continuous ponding (Alberta Agriculture 1980). Improvement of soil drainage may be needed for leaching treatment (Alberta Environment 2001, Lee et al 2013). Tillage and paratilling can improve soil permeability by breaking up surface crusts. Drains will be required if soil hydraulic conductivity does not allow for water movement through the root zone, where there is risk of adverse effects from movement of leached salts and where topography and shallow ground water prevent sufficient drainage. Subsurface drains may be slotted plastic pipes, buried vaults or mole drains (subsurface drainage pathways in fine textured soils with a specialized plough). The drains utilize gravity or a pump to discharge water to a collector. Leachate can be collected through subsurface drains and/or trenches, bell holes and storage tanks. If soils are also sodic, sodium must be replaced by calcium on the surface prior to leaching (see amendments).

To achieve remediation of soil salinity a profile of the soil salt balance should be undertaken. This refers to a summary of all salt inputs and outputs for a specified period of time. If inputs exceed outputs then salt is certainly accumulating (Quirk and Schofield 1955). Reclaiming salinized soils by leaching will not be successful unless lateral ground water drainage is sufficient and rapid enough to carry away excess salts. Unless the water table is very deep, repeated soil leaching without accompanying drainage will gradually raise the water table and salts will again invade the soil profile rooting zone.

6.4. Amendments

Salt affected soils can be remediated through addition of amendments. Amendments include calcium salts (calcium chloride, gypsum) and acids or acid producers (sulfur, sulfuric acid, iron sulfate, aluminum sulfate, calcium polysulfide) (Richards 1954). Calcium chloride is more soluble and more expensive than gypsum. Ground limestone can be used as a calcium salt amendment. The effectiveness varies with soil pH; calcium carbonate is more soluble at low pH. Common amendments for sodic soils such as calcium sulfate, calcium nitrate, calcium chloride and magnesium sulfate provide soluble calcium or magnesium cations (Ashworth 2007). When calcium carbonate or magnesium carbonate are present, acids such as sulfuric acid can be added to release calcium or magnesium. Phosphogypsum, a by product of phosphate fertilizer production, can be used as an amendment to decrease soil salinity and sodicity with little impact on trace element concentrations (Liang et al 1995).

Amendments can be surface applied, incorporated into soil, applied in irrigation water (Richards 1954) or hydroseeded (Vavrek et al 2004). Amendment application after leaching means more of the supplied calcium is adsorbed onto exchange sites but will cause increased sodium adsorption ratio and possibly decreased soil permeability. Sulfur amendments should be kept damp and allowed to oxidize and form gypsum before leaching is conducted (Richards 1954).

If soils are sodic, sodium must be replaced on the soil surface prior to leaching. Calcium or magnesium can facilitate sodium removal from exchange sites (Karamanos 1996), thus lowering sodium adsorption ratio. To remediate sodic soils, calcium is added to replace sodium on soil particles. Calcium can be added in various forms. Commonly used solid calcium amendments are gypsum ($CaSO_4 \cdot 2H_2O$) and calcium nitrate ($Ca(NO_3)_2$). Calcium amendments may be dissolved and added to the soil in liquid form to increase depth of addition and reduce treatment time. When doing this, care must be taken to prrevent a rise in exchangeable sodium percentage (Yan et al 2015). Saline-alkali soils generally have an exchangeable sodium percentage greater than 15 and, if leached, tend to disperse and have high pH values. Therefore, to reclaim saline-alkali soils, in addition to leaching, they need to be treated with calcium salts (gypsum) to replace excess exchangeable sodium. Calcium allows plants to maintain potassium transport and potassium or sodium selectivity and increases nitrate assimilation under saline conditions (Vavrek et al 2004).

Ashworth et al (1999) compared one method of calculating gypsum requirement based on exchangeable sodium and sodium in soil solution with four methods that did not directly include sodium in soil solution. Only the method based on total soluble sodium was consistent with sodium adsorption ratio and electrical conductivity; it may be most appropriate for Alberta sites which do not have sufficient precipitation and drainage for complete leaching of excess sodium. Graveland and Toogood (1963) found exchangeable sodium percentage of samples from the Bn horizon of seven non saline Alberta solonetzic soils was reduced after leaching with gypsum solutions. Leaching with tap water or low concentration gypsum solutions resulted in decreased hydraulic conductivity while leaching with high concentration gypsum solutions did not.

De Jong (1982) found gypsum treatment for soils contaminated with sodium chloride was more effective at promoting percolation when incorporated into the soil than when surface applied. Visual evidence of dispersion was observed near the top of soil columns with surface applied gypsum. Calcium nitrate was more effective when surface applied than when incorporated because its high solubility resulted in rapid loss during leaching when incorporated. For the first few pore volumes of leachate, concentrations of sodium and chloride were similar; sodium concentrations were lower than chloride concentrations in subsequent pore volumes due to retention on exchange sites. Salt removal efficiency decreased over time, possibly due to limited exchange between inter and intra aggregate pores.

Webster et al (1983) studied sodium chloride brine (electrical conductivity 60 dS/m) contaminated forest soils in the field. Flushing with water reduced seepage water electrical conductivity below 1 dS/m. Broadcasting gypsum following flushing improved subsequent salt removal from the 0 to 30 cm depth, reduced sodium adsorption ratio to 3.5 at 0 to 15 cm depth (6.0 for flushing only and 7.8 for no treatment), maintained soil stability and reduced plant mortality. Fertilizer application increased live plant cover.

In a study by Nielsen (2013) using brine contaminated soils, the maximum calcium nitrate application rate under Saskatchewan guidelines did not provide enough calcium to reduce initial sodium adsorption ratios of 142 and 172 to an acceptable level. When gypsum and calcium nitrate were added to supply the same amount of calcium, gypsum was more effective in reducing sodium adsorption ratio. Carter and Pearen (1989) found that 6 years of field application of calcium sulfate (2.24 t/ha/y) and ammonium nitrate (224 kg/ha/y) resulted in sodium adsorption values of 1.2 in the A horizon and 1.7 in the B horizon relative to 12.7 and 29.0, respectively, for the control. Merrill et al (1990) treated brine contaminated soil columns with calcium chloride followed by leaching with distilled water or saline water. Leaching with saline water maintained greater soil permeability and allowed percolation of a greater volume of water. As a result, 92 % of exchangeable salts were removed from the 0 to 16 cm depth by saline water leaching relative to 89 % by distilled water leaching.

A review by Lakhdar et al (2009) found composted municipal solid waste can increase soil organic carbon, promote flocculation, decrease bulk density and increase salt removal by leaching. Compost provides slowly exchangeable nutrients, stimulates microbial activity including nitrification and can increase phosphorus bioavailability. Risks of compost amendment are induction of anaerobic conditions and contamination with substances such as metals, pesticides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxins and furans.

A review by Diacono and Montemurro (2015) found organic amendments promote aggregation in salt affected soils which increases porosity, infiltration and water holding capacity. Organic amendments can promote various enzyme activities. Multiple years of manure application can result in increased salinity and sodicity. Although composting manure can concentrate salts due to water loss, Miller et al (2005) found its application did not result in a greater increase in soil electrical conductivity than that resulting from fresh manure application.

Harris et al (2005) found treatment with hay resulted in greater reduction in sodium concentration than treatment with gypsum at a brine spill site with subsurface drainage installed. The hay treatment promoted revegetation while the gypsum treatment remained nearly bare. Tejada et al (2006) amended salt affected soil (electrical conductivity 9.1 dS/m, exchangeable sodium percentage 15.7) with crushed cotton gin compost and poultry manure and found that with poultry manure there was greater spontaneous vegetation cover (70 to 80 %) than with crushed cotton gin compost (53 to 66 %) and unamended soil (8 %).

Thomas et al (2013) used sawdust biochar to amend potting soils which were then surface treated with 30 g/m^2 sodium chloride road salt. Nearly all velvet leaf and self heal died within 10 days in pots with 0 or 5 t/ha biochar. Survival with 50 t/ha biochar was 100 % over the 63 day experiment for velvet leaf and for self heal was 80 % until day 40 when mortality began increasing. Biochar is thought to have adsorbed salts.

Chelating agents are compounds which form stable complexes with multiple cations. Ashworth (2007) found that adding 0.30 g ethylenediamine tetraacetic acid (EDTA) to 65 g of Alberta soil with initial sodium adsorption ratio 9.4 and electrical conductivity 0.9 dSm caused a decrease in sodium adsorption ratio to 4.8 and an increase in electrical conductivity to 3.8 dS/m. Adding 0.20 g calcium chloride and 0.25 g magnesium sulfate caused smaller decreases in sodium adsorption ratio (8.6 and 8.3, respectively) and larger increases in electrical conductivity (9.1 and 4.9 dS/m, respectively). Saturated hydraulic conductivity increased from $5.2 \pm 0.23 \times 10^{-6}$ cm/s to $11.3 \pm 1.50 \times 10^{-6}$ cm/s upon addition of 10 kg/m^3 EDTA. In a column experiment by Zhang et al (2008), 5 cm coarse wheat straw at the soil surface prevented salinization of surface soil with electrical conductivity 22 dS/m after sodium chloride solution was in contact with the column bottom for 30 days.

6.5. Electro Kinetic

Soil salinity may be addressed by electro kinetic treatment. In this in situ technique, a direct current is applied to an area of soil spanned by electrodes (Cho et al 2009, Lee et al 2013).

Electro kinetic treatment moves salts through the soil by two primary mechanisms: electro migration, movement of ions within pore water, and electro osmosis, transport of water from the anode to the cathode. The electrodes induce hydrolysis reactions which produce hydrogen (H^+) and hydroxyl (OH^-) ions and decrease soil pH to < 3 at the anode and increase soil pH to 8 to 12 near the cathode (Cho et al 2009). Electro kinetic remediation is more effective than most other techniques in soils with low permeability and fine texture (Essa et al 2013). In a laboratory experiment using a voltage of 1 V/cm, Cho et al (2009) reported significant transport of anions towards the anode but no transport of cations. Nitrate transport and removal was greatest due to its high solubility and conversion to nitrogen gas at low pH. Following electro kinetic treatment, electrical conductivity was lower near the cathode due to transport and accumulation of salts. Using pulses of energy instead of a constant current can substantially decrease energy consumption while achieving the same amount of salt removal (Lee et al 2013).

6.6. Bioremediation And Phytoremediation

Soil reclamation, phytoremediation and mycorrhizal fungi augmentation is a cost effective alternative to soil removal and replacement and establishment of native plant communities and ecological functions may be the best measures of remediation success (Vavrek et al 2004). Bioremediation aspects of salt affected soil remediation are inextricably associated with plants and thus with phytoremediation.

Vegetation can be used to promote leaching through the entire root zone rather than just the soil volume with calcium added (Qadir and Oster 2004). Oxidation of root exudates increases the partial pressure of carbon dioxide in the root zone. Carbon dioxide dissolves to form carbonic acid (H_2CO_3) which dissociates and releases protons which then react with calcite ($CaCO_3$) naturally present in soil to produce calcium ions. Calcium replaces sodium on soil surfaces and allows it to be leached through the profile. Organic acids and protons released by plants can encourage dissolution of calcite. Plants increase hydraulic conductivity of soil creating macro pores, increasing aggregate stability, and removing air trapped in conducting pores. Plants contribute nutrients to soil which can be lost during leaching. Water used by plants is unavailable to percolate through the soil and transport salts which accumulate in areas of discharge and evaporation (Mankin and Koelliker 2000). In a field study by Kushiev et al (2005), land in the Aral Sea basin abandoned due to salinization was planted with licorice for four years. Following treatment, the land supported increased germination and yield for wheat and cotton crops relative to bare fallow land. Treatment decreased extractable anion and cation concentrations in the soil and maintained or increased depth to the water table.

Vegetation can remediate salt affected soils through phytoextraction. Halophytes are plants that exclude salts from their tissues, plants that accumulate salts in their tissues or plants that conduct and excrete salts into the atmosphere through salt glands (Jesus 2015). Salt accumulator plants with high above ground biomass can remove the most salt from soil (Qadir and Oster 2004). Estimated salt uptake ranges from 91 kg/ha/y for birdsfoot trefoil to 5,376 kg/ha/y for shoreline purslane (Jesus 2015). Perennial plants are desirable as they have longer growing seasons for active salt uptake. Phytoextraction is dependent on salt concentration with greater reduction in electrical conductivity with high initial electrical conductivity. Greater reduction in sodium adsorption ratio occurs at lower initial sodium adsorption ratio, likely due to greater hydraulic conductivity. Phytoextraction and leaching can be combined using salt accumulators to withstand temporary saturated conditions (Qadir and Oster 2004). Providing more water than required for plant use means surplus water is available for transporting salts downwards out of the soil profile.

Use of plant growth promoting rhizobacteria can enhance plant growth and soil remediation (Chang 2007, Greenberg et al 2007, Zhong 2011, Chang et al 2014). Plant growth promoting rhizobacteria containing the enzyme 1-amino-cyclopropane-1-carboxylate (ACC) deaminase reduce the stress hormone ethylene in plants, thereby improving plant growth and increasing foliar tissue sodium concentrations. In the field, rhizobacterial isolates increased oats biomass by as much as three times that of control (both with electrical conductivity 24 dS/m) and doubled barley biomass (electrical conductivity 4.4 dS/m) (Chang et al 2014). Similar results were found in a greenhouse for shoot and root biomass when grown in soil with electrical conductivity 9.4 dS/m. In a field study using barley, oats, tall fescue and rye grass, based on an accumulation rate of 1580 kg/ha/y sodium chloride, the top 50 cm of soil could be remediated in 7 years relative to 15 years without plant growth promoting rhizobacteria (Chang 2007). In the greenhouse, plant growth promoting rhizobacteria increased barley and fall rye germination and biomass by 100 % in salt affected soil from Alberta (electrical conductivity 2 to 10 dS/m) and Saskatchewan (13 to 50 dS/m) (Greenberg et al 2007). Physiologically, plant growth rhizobacteria increased proline concentrations, lowered membrane leakage and restored chlorophyll fluorescence parameters to pre salt stress conditions in annual rye grass (electrical conductivity 10 dS/m) (Zhong 2011).

Inoculation of plants with mycorrhizal fungi enhanced plant growth and remediation of salt affected soils (Colgan et al 2002, Mushin and Zwiazek 2002, Asghare et al 2005, Yi et al 2008). Perennial rye grass germination, establishment and survival increased in sodium chloride (electrical conductivity 10 and 16 dS/m) contaminated soils when amended with the arbuscular mycorrhizal fungus, *Glomus intraradices*, relative to the unamended treatment (Colgan et al 2002). In brine with electrical conductivity 16 dS/m, no species germinated, possibly due to presence of some hydrocarbons or differences in salts. White spruce growth, transpiration and root respiration were reduced by a 25 mM sodium chloride treatment regardless if amended with the mycorrhizal fungi, *Hebeloma crustuliniforme* (Mushin and Zwiazek 2002). Mycorrhizal fungi inoculation increased shoot and root biomass, number of lateral branches, nitrogen and phosphorus tissue concentrations, chlorophyll content and water conductance relative to without. Sodium in shoots and roots was not greater with inoculation suggesting that while mycorrhizae increase white spruce tolerance of saline conditions, phytoremediation is not occurring. Inoculation with *Hebeloma crustuliniforme* or *Laccaria bicolor* increased water conductance of aspen and birch and also increased sodium and chloride concentrations in shoots and roots. Aspen inoculated with *Hebeloma crustuliniforme* had double the sodium concentration in roots than in non inoculated treatments (Yi et al 2008).

Halophytic saltbush species are commonly used for phytoremediation of salt affected soils (Ungar 1996, Keyes and Mott 1999, Howes Keiffer and Ungar 2001, 2002, Ashghare et al 2005, Young et al 2011). Armed and four wing saltbush significantly reduced soil electrical conductivity from 23.9 to 14.3 to 20.2 dS/m and sodium concentrations from 3070 to 1576 to 2600 mg/kg depending on species and accession (Keyes and Mott 1999). These species are palatable to cattle and wildlife and biomass could be harvested for consumption. Prostrate saltbush significantly reduced soil sodium over one growing season on low salinity (0.5 % sodium chloride, electrical conductivity 8 to 12 dS/m) but not in high salinity sites (2 % sodium chloride, electrical conductivity 20 to 35 dS/m) (Howes Keiffer and Ungar 2001). At high salinity sites, red samphire and western sea blite produced the greater decrease in sodium. Reductions for any species were not more than 15 %.

In a related study, the same species sown in spring were negatively affected by high electrical conductivities but not when autumn sown which accumulated more sodium than spring sown. Leaching resulted in a 44 % decrease in soil sodium over 4 years, but in plots seeded with halophytes, there was a 59 % decrease, the difference attributed to plant uptake (Howes Keiffer and Ungar 2002). In the greenhouse, spear orach accumulated the most sodium of fourteen halophytic species native to the Canadian prairies (Young et al 2011). In a subsequent field study, spear orache did not compete effectively with weeds on saline sites, but did when soil was compacted as there was little competition. Ungar (1996) also reported spear orache was best suited for low to moderately saline sites with sodium chloride less than 1 %.

Singleton et al (1982) found it was possible to develop saline tolerant rhizobia species that will successfully infect and effectively nodulate alfalfa and other clovers growing under saline conditions. The National University of Uzbekistan has isolated salt tolerant bacterial strains (*Pseudomonas extremorintalis*). They produce antibiotics that plants use to defend themselves against fungi, trigger the rooting process and produce nodulation factors which give vegetation a better chance to survive. Plants provide exudates which are useful for bacteria. Thus these may be useful in bioremediation of salt affected soils.

The role of microorganisms in overcoming biotic and abiotic stresses is becoming increasingly known and work in plant growth promoting rhizobacteria mediated tolerance to abiotic stresses, including salinity, has been reviewed (Yang et al 2009, Dodd and Perez-Alfocea 2012). The term, induced systemic tolerance, has been proposed for plant growth promoting rhizobacteria induced physical and chemical changes that result in enhanced tolerance to abiotic stresses. These rhizobacteria influence plant growth indirectly by reducing plant pathogens and directly through phyto hormone production (auxin, cytokinin, gibberellins). Inoculations with arbuscular mycorrhizal fungi will also improve plant growth under salt stress (Cho et al 2006).

In the last decade bacteria from the genera Rhizobium, Bacillus, Pseudomonas, Pantoea, Paenibacillus, Burkholderia, Achromobacter, Azospirillum, Microbacterium, Methylobacterium, Variovorax and Enterobacter have been described as providing tolerance to different abiotic stress environments for various crop plants (Grover et al 2011). The protection mechanisms have involved production of indole acetic acid, gibberellins and some as yet unknown compounds resulting in increased root mass, root surface area and number of root tips. This leads to an increased uptake of nutrients which will improve overall plant health under stressed conditions (saline conditions). Plant growth promoting bacteria, such as those just listed, have improved growth of tomato, pepper, canola, bean and lettuce crops under saline conditions (Barassi et al 2006). Other strains are known to produce cytokinin and antioxidants which result in abscisic acid accumulation and degradation of reactive oxygen species. This, in turn, is linked with oxidative stress tolerance (Stajner et al 1997).

Plants treated with exo-polysaccharide producing bacteria display increased resistance to water and salinity stress due to improved soil structure (Sandhya et al 2009). Exo-polysaccharide can also bind to cations including sodium and make them unavailable to plants under saline conditions (Chen et al 2007). Yao et al (2010) reported that inoculation with *Pseudomonas putida* Rs 198 promoted cotton growth and germination under salt stressed conditions. Another strain of *Pseudomonas putida* when used to inoculate wheat enhanced germination and improved nutrient status of wheat plants while in saline stress. Arthrobacter strains have been used as inoculants to address the adverse effects of salinity on wheat growth with an increase of dry biomass, total soluble sugars and proline content (Jha et al 2011).

6.7. Risk Assessment

Worldwide, massive areas of land can be considered contaminated to some degree. With such a large number of sites requiring treatment, a method is needed to determine the threshold at which a site poses an unacceptably high risk to human or environmental health (Petts et al 1997). Risk management stems from the principles that funding for remediation projects must be prioritized and that decisions should be made objectively even though not all information is known for most sites. Risk management is used to evaluate a risk, determine whether it is acceptable and minimize risk if needed (Jackson and Eduljee 1996).

The main components of risk management can be described as risk assessment and risk reduction (Petts et al 1997). Risk assessment is the estimation and evaluation of the risk posed by a site (Jackson and Eduljee 1996). It includes identification of contaminated sites, evaluation of hazards posed by the contaminants present and the likelihood and acceptability of exposure of receptors to the contamination (Petts et al 1997). Risk assessments are used to determine the degree to which a contaminated site poses an unacceptable risk to receptors and to establish remediation criteria (LaGoy 1994). Risk assessment can be used to determine appropriate land uses for a site and to evaluate success of a remediation effort. Risk reduction involves selection, implementation and evaluation of strategies designed to minimize or eliminate harm caused by receptor exposure to contamination (Petts et al 1997). These strategies may focus on reducing and/or removing contamination or limiting receptor exposure.

Risk management is based on the concepts of source, pathway and receptor. Sources are contaminated or potentially contaminated sites which can be classified as point, where contaminant release is direct and relatively easily identifiable, or non point, where contaminant release is indirect and spread over large areas (Petts et al 1997). Examples of point sources include chemical spills or waste disposal while non point sources include runoff of pesticides and emissions from vehicles. Pathways are the routes by which contaminants are transported in the environment and include translocation processes such as leaching and runoff, transformation processes such as sorption and degradation, and intake processes such as inhalation and ingestion. Pathways are dependent upon the nature of the contaminant and environmental conditions. Receptors are natural or anthropogenic entities which may be negatively affected by contamination. Receptors are also known as targets and include abiotic environmental components, plants, animals, humans, materials, infrastructure and socioeconomic considerations. Receptors can be harmed through direct effects of contaminated media or indirect effects of materials contaminated by contaminated media. Risk occurs when sources, pathways and receptors are linked.

Basic risk management has been used in decision making for thousands of years; modern formalization occurred in the 1930s with chemical assessments, 1960s and 1970s with nuclear assessments, and 1970s and 1980s with cancer assessments (LaGoy 1994, Petts et al 1997). Modernization of risk assessment introduced calculation of very small risks (LaGoy 1994).

Site specific risk assessments reduce uncertainty in estimating exposure and risk by using more accurate information than standard values, which generally lowers general risk estimates (Hattemer-Frey and Lau 1996). In a site specific risk assessment, generic risk assessment assumptions, models and toxicological data are combined with site information to estimate exposure and risk (LaGoy 1994). Site information includes contaminant concentrations, contaminant forms, hydrology, geology, topography, climate and receptor presence. Information on the environment surrounding the contaminated site is also important. Numerous contaminants are often detected at a given site; the key chemicals of concern may be selected based on their high likelihood to pose an unacceptable risk. Contaminants found at elevated concentrations in background locations or infrequently detected on site would likely not be included as key chemicals of concern. Potential operable pathways can be determined based on site information and potential end land uses. Direct measurements and models can then be used to estimate contaminant exposure point concentrations and uptake concentrations via different pathways (LaGoy 1994, Hattemer-Frey and Lau 1996). Exposure information and hazard information are combined to determine risk (LaGoy 1994).

Uncertainty arises in risk management due to variability in site conditions and receptors and incomplete exposure and toxicity information (LaGoy 1994, Hattemer-Frey and Lau 1996). Due to its use in policy, assumptions in risk assessments are made to give conservative results where findings are most likely over protective (LaGoy 1994). Another method of dealing with uncertainty is to determine a central or average risk and a worst case scenario risk (Jackson and Eduljee 1996).

Risk assessments and risk management have become a relatively common component of remediation program planning. This is particularly so for situations where active remediation would do more harm than management of the risk. The risk management approach often includes a passive remediation technique such as bioremediation or relies completely on natural attenuation of contaminants and monitoring.

7. ANALYSIS, KNOWLEDGE GAPS AND RECOMMENDATIONS

7.1. Analysis

Soil salinity is a prevalent and complex issue. Salts, whether natural or a result of anthropogenic activity, change soil physical, chemical and microbiological properties. How they change soil properties and the magnitude of the change depends on type and concentration of salts and specific ions. Sodium chloride is one of the most common salts; however, other chloride salts (calcium chloride, magnesium chloride) and sulfate salts (sodium sulfate, magnesium sulfate) are present in some Alberta soils. Sodium is the most detrimental ion to soil quality by causing dispersion and clay swelling, leading to poor soil structure and reduced permeability. Interactions with other ions affect plant response. Few soils are affected by only one salt and the interaction among salts and ions can determine plant species response and ability to tolerate the saline conditions. Sodium accumulation in shoots results in necrosis and in the presence of chloride, sodium accumulation is accelerated. Sodium chloride causes reduced soil nitrogen immobilization, nitrification and mineralization. Most plants are more sensitive to chloride salinity than sulfate salinity. Measures of salinity vary depending on researcher, land manager or jurisdiction. While most guidelines rely on electrical conductivity and sodium adsorption ratio for assessment of saline sites, few studies or salt tolerance indices include sodium adsorption ratio in their assessments. Due to the lack of data we cannot draw conclusions on the interrelationship of sodium adsorption ratio, saline soil and impacts on plants in this report. Research has shown that the type and concentration of soluble salts and specific ions are as important, or potentially greater, than electrical conductivity or sodium adsorption ratio, in determining salt impacts on soil and plants; however, they are not commonly or consistently measured.

Due to the plethora of literature on saline soils worldwide, we primarily focused this report on literature from the western regions of Canada and the United States. While not wholly summarized in this document, literature from other regions and countries was reviewed and findings were similar. Our approach is further supported by the literature, as plant species, seed source, soil type and environmental factors greatly influence impacts of salt contamination. There is much research on salt impacts on ground water, however, the focus is on immediate impacts on soil and plants. As part of the reclamation process, longer term impacts and the role of ground water and off site impacts must be considered. Experimental research has been focused mainly on crops and some forages and boreal plant communities. There is very little to no research on prairie plant communities.

Some salts move within the soil profile and, therefore, concentrations fluctuate seasonally and annually. Salt affected soils may appear to be remediated, particularly in the upper soil horizons, but over time and with increased precipitation or irrigation, salts may rise again to the surface, killing or damaging vegetation. Salt affected soil remediation must consider these pathways of movement within the soil profile as well as laterally, potentially resulting in off site impacts.

Research shows that salts can negatively affect plants at all stages of development and at electrical conductivities as low as 0.5 dS/m. Salt tolerance is a term widely used to describe the ability of a species to withstand saline conditions. However, there is no clear or consistent definition as to what saline conditions are or what acceptable tolerance thresholds are for plant growth and productivity. Salt tolerance must be based on a specific plant measure and an acceptable decline in this measure, if any is permitted. When assessing the risk of road salt impacts on vegetation, researchers have based threshold and critical toxicity values on declines in plant response of 0 to 50 % (Cain et al 2000). In natural plant communities, even small changes in vegetation abundance and composition can have negative consequences for ecosystem form and function and therefore resistance and resilience. Seemingly healthy vegetation growing in salt contaminated sites in the short term may not be sustainable if recruitment is inhibited. Rather than focussing on determining salt tolerance for species, efforts may be better spent on assessing community response to salinity and determining effective ranges of salinity for associated site and environmental conditions.

There are a multitude of salt tolerance indices and rankings for crops of the prairie regions of Canada (Alberta Agriculture and Forestry, Agriculture and Agri-Food Canada) and North America (US Salinity Laboratory Research Databases). The yield response curve is widely used (Maas and Hoffman 1977, Maas 1993). The curve contains two lines, the first is yield under non saline conditions and the second yield with increasing salinity as measured by electrical conductivity. The threshold point is where the yield under saline conditions crosses the non saline yield line. The slope of the saline line is presented to indicate a percent change in yield per 1 dS/m conductivity. Based on this, Maas (1993) developed general salt tolerance categories ranging from sensitive to moderately sensitive to moderately tolerant to tolerant. Due to the multitude of factors which impact plant response to salinity, this index is meant as a relative measure to compare species versus an absolute value. The Canadian Salt Tolerance Facility has developed a salinity index for crops based on the EC_{50} (Steppuhn 2013a). The EC_{50} is the electrical conductivity at which a 50 % decline in crop yield, or other performance measure, is observed. The maximum electrical conductivity at which a crop can survive before complete mortality is sometimes reported (Fowler and Hamm 1980). A range of values in the continuum of salt and sodium stresses may represent the tolerance or sensitivity of a plant better than a single critical value because the intensity of salt stress is not independent of many other factors determining yields (Läuchli and Epstein 1990). The salt guidelines identify certain plant species and their respective threshold electrical conductivity (Department of Agriculture Salt Tolerance Databases USDA 2015). This demonstrates the relative sensitivity of certain plants to soil salinity. However, these data are based on electrical conductivity measurements, not specific ion concentrations.

An electrical conductivity of 4 dS/m has long been accepted as the threshold above which most plants are negatively affected by salts. This value has been arbitrarily established. Recent research findings do not support this value. Increasing levels of electrical conductivity are generally associated with decreased plant performance. Even plants that can tolerate higher electrical conductivities experience decreases in plant growth or function, the rate may just be less than that of other species. New cultivars are being produced to withstand higher electrical conductivities and to produce increased yields. Some agronomic and native glycophytes can survive in soils with very high electrical conductivities. Crop salt tolerance ratings have long identified that there is a range of electrical conductivities which define saline soil and plant tolerance, but this has not often been incorporated into remediation and reclamation criteria.

Naturally saline soils exist in Alberta and support a diversity of plants; however, it is a select suite of species that can tolerate these conditions. Even within these sites, plant communities are organized along a salinity gradient. Saline sites need to be remediated so the appropriate plant community can be re-established to maintain landscape diversity and function. Leaching combined with amendments can remediate soils with sodium chloride. Organic amendments increase vegetation growth which may aid soil remediation. Natural recovery may be possible on some salt affected soils; however, in general this has only been reported on low salinity sites.

End land use and land management are key factors in determining the successful recovery of vegetation on salt affected soils. In agricultural areas, there are many salt tolerant cultivars that can be sown, though seeding rates may need to be increased to compensate for inhibited germination. Salt tolerant crops and forages do accumulate sodium, chloride and sulfate and this may be a concern on grazing lands or where there is high wildlife use. These tolerant cultivars may assist in remediating the soil, although the research to date has been focussed on tolerance versus their phytoremediation abilities. Agronomic species and cultivars are not appropriate for revegetation of many areas of the province. Sourcing seed adapted to saline conditions is beneficial. Pre-seeding irrigation can improve germination rate on many salt affected soils. If a few native halophytes can be included in a seed mix, this could assist in remediating the soil while establishing a diverse plant community.

In reclaiming disturbed sites in Alberta, the aim is to achieve equivalent land capability. The general definition of equivalent land capability indicates "that the ability of the land to support various land uses after conservation and reclamation is similar to that ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be identical" (Alberta Government 2014b). The definition of equivalent land capability thus potentially allows for some flexibility in achieving reclamation success, indicating that electrical conductivity and sodium adsorption ratio values could vary from specified criteria or other criteria could be used providing pre-disturbance land use can be supported.

At the current time in Alberta, a site is determined to meet reclamation criteria based on, among other things, electrical conductivity and sodium adsorption ratio values. The electrical conductivity and sodium adsorption ratio values apply to all sites, regardless of naturally occurring levels and vegetation tolerance to salts. To determine whether the criteria should be modified to address the issue of salt affected soils in specific circumstances, there needs to be a basic understanding of the existing criteria and a determination of whether there are alternative approaches to achieving reclamation success. An alternative would be to determine ranges of acceptable ion concentrations that would still achieve equivalent land capability based on the specific vegetation species that would be grown on the specific site. If a more species and ion type and concentration specific set of criteria can be developed, it will provide alternatives for achieving reclamation success.

7.2. Knowledge Gaps

- The current approach to determine if salt affected soils meet reclamation criteria only considers electrical conductivity and sodium adsorption ratio. There may be an alternative method of assessing whether a site meets reclamation objectives based on vegetation response to soil conditions. An alternative method to assess reclamation success in specific circumstances with strong supporting data, could lead to modifications to the current reclamation criteria.
- It is not known how much of a risk exists if subsoil is not remediated when the site already had been successfully revegetated.
- Research is lacking on plant response to sodium adsorption ratio values.
- Research is lacking on interrelationships of electrical conductivity, sodium adsorption ratio and soluble salts and specific ion concentrations and impacts on plants.
- Research is lacking on specific ion impacts on plants and plant communities at different

concentrations alone and in combinations. Sodium is detrimental to plant growth but little is known about effects of other ions.

- Identifying the most common ions that are of concern for soil quality and revegetation success in Alberta is required to focus changes to reclamation criteria.
- Research is lacking to clearly indicate whether plant response can be categorized by cation versus anion, monovalent versus multi-valent ions or if it must be ion specific.
- Field research is lacking and research under controlled conditions does not take into account climatic and site variability.
- Research is lacking that experimentally compares effect of soil type or environmental conditions on plant response to salinity.
- Salt tolerance ratings are highly variable and their basis is often unclear. It is difficult to determine what an acceptable rate of injury or mortality is and whether it varies with species.
- Salt tolerance is dependent on the measure and stage of development, however, it is not known if data from a few measures or stages of development are reliable to identify overall salt tolerance for a species.
- The long term impacts of different salts and ions at different concentrations under different soil properties and conditions need to be investigated.
- Sound, scientifically grounded data are required to develop reliable reclamation criteria.

7.3. Recommendations

Replicated, experimental salt contamination research repeated at multiple field sites would provide a better understanding of how oil and gas specific contamination may affect plants and plant community development, particularly plants other than forage and cereal crops. This research could be comprised of two main components.

The first research component would use several existing sites in areas of interest in Alberta. Collection and assessment of detailed soil and vegetation data from sites that are known to have salinity issues, would not meet current reclamation criteria, yet have good revegetation, would help to determine the relationship between soil properties relating to salinity and plant community health. These sites would be identified with the assistance of industrial partners and government regulatory personnel. They could be of various ages, reclamation techniques, soils, vegetation and management regimes. They would be assessed to determine plant species and community health in the absence of reclamation criteria achievement.

The second research component would establish three to five research sites in areas of interest across Alberta in a replicated field experiment. The types and levels of salt contamination, plant species (mainly grasses and forbs that are not forage or cereal crops) and seed sources, and measures of contamination and impact on plants would be standardized across sites for detailed comparisons. Multiple measures of salinity would be used including electrical conductivity, sodium adsorption ratio, pH, totals salts and individual soluble salts. A meteorological station would be established at each research site to monitor precipitation. Treatments would include salt type, salt concentration and timing of contamination. Changes in soil properties including specific ions, electrical conductivity, sodium adsorption ratio, pH, exchangeable sodium percentage, cation exchange capacity and plant measures including germination, establishment, height, growth rate, shoot biomass and foliar tissue salt concentrations would be assessed over 2 to 5 years. A variety of species would be selected for the study representing all plant forms (forbs, grasses, shrubs, trees).

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Table 1. List of plant species cited in the report.

Common Name	Scientific Name
Agricultural Crops	
Alfalfa	*Medicago sativa* ssp. *sativa* or *M. sativa* ssp. *falcata*
Barley	*Hordeum vulgare* L.
Bean, pinto	*Phaseolus vulgaris* L.
Beets, sugar	*Beta vulgaris* subsp. vulgaris
Camelina	*Camelina sativa* L.
Canola	*Brassica* sp. L.
Corn	*Zea mays* L.
Flaxseed	*Linum usitatissimum* L.
Lentils	*Lens culinaris* Medik.
Mustard, yellow	*Sinapis alba* L.
Oats	*Avena sativa* L.
Peas, yellow or green field	*Pisum sativum* L.
Quinoa	*Chenopodium quinoa* Wild.
Rye, annual	*Lolium multiflorum* Lamarck
Rye, fall or spring	*Secale cereale* L.
Rye, perennial	*Lolium perenne* L.
Soybean	*Glycine max* (L.) Merr.
Wheat	*Triticum aestivum*
Wheat, durum	*Triticum durum* L. or *Triticum turgidum* L.
Forages	
Blue grass, alpine	*Poa alpina* L.
Blue grass, kentucky	*Poa pratensis* L.
Brome, meadow	*Bromus riparius* Rehm.
Brome, smooth	*Bromus inermis* Leyss.
Fescue, creeping red	*Festuca rubra* L.
Fescue, hard	*Festuca brevipila* Tracey
Fescue, sheep	*Festuca ovina* L.
Fescue, tall	*Festuca arundinacea* Schreb.
June grass	*Koeleria macrantha* (Ledeb.) J.A. Schultes f.
NewHy	*Elytrigia repens* (L.) Nevski x *Pseudoroegenia spicata* (Pursch) A. Love
Timothy	*Phleum pratense* L.
Wheat grass, green	*Elymus hoffmannii* Jensen and Asay
Wheat grass, northern	*Elymus lanceolatus* (Scribn. & Smith) Gould
Wheat grass, slender	*Elymus trachycaulus* (Link) Gould ex Shinners
Wheat grass, tall	*Elytrigia elongata* (Host) Nevski
Wheat grass, western	*Pascopyrum smithii* (Rydb.) Love
Wild rye, altai	*Leymus angustus* (Trin.) Pilger
Wild rye, dahurian	*Elymus dahuricus* Turcz. Ex Grieseb.
Wild rye, russian	*Psathyrostachys juncea* (Fisch.) Nevski
Wheat grass, crested	*Agropyron cristatum* (L.) Gaertner
Redtop	*Agrostis gigantea* Roth
Graminoids	
Foxtail barley	*Hordeum jubatum* L.
Northern reed grass	*Calamagrostis inexpansa* A. Gray
Nuttall's alkalai grass	*Puccinellia nuttalliana* (Schult.) A.S. Hitchc.
Reed canary grass	*Phalaris arundinacea* L.

Table 1. List of plant species cited in the report (continued).

Common Name	Scientific Name
Rush, wire	*Juncus balticus* Willd.
Salt grass, inland	*Distichlis stricta* (Torr.) Rydb.
Seaside arrow grass	*Triglochin maritima* L.
Sedge, water	*Carex aquatilis* Wahlenb.
Forbs	
Amaranth, prostrate	*Amaranthus blitoides* S. Watson
Aster, white heath	*Aster ericoides* L.
Blueberry	*Vaccinium myrtilloides* Michx.
Blue bur	*Echium vulgare* L.
Buffalo berry	*Shepherdia canadensis* (L.) Nutt.
Bunchberry	*Cornus canadensis* L.
Cattail	*Typha latifolia* L.
Common pepper grass	*Lepidum densiflorum* Schrad.
Cranberry, bog	*Vaccinium vitis-idaea* L.
Cranesbill	*Geranium bicknellii* Britt.
Goosefoot	*Chenopodium* sp. L.
Kochia	*Kochia scoparia* (L.) Schrad.
Labrador tea	*Ledum groenlandicum* Oeder
Perennial sow thistle	*Sonchus arvense* L.
Pink wintergreen	*Pyrola asarifolia* Michx.
Plains prickly pear cactus	*Opuntia polyacantha* Haw.
Rat root	*Acorus americanus* Raf.
Red swampfire	*Salicornia rubra* Nels.
Russian thistle	*Salsola pestifer* Nels.
Saltbrush, armed	*Artiplex acanthocarpa* (Torr.) Wats.
Saltbrush, four winged	*Atriplex canescens* (Pursch) Nutt.
Sagewort, prairie	*Artemisia frigida* Willd.
Saltbrush, prostrate	Atriplex prostrata Bouch. *ex* DC.
Saltbrush, spear	*Atriplex patula* L.
Saltbrush, spear	*Atriplex patula* var. *subspicata* (Nutt.) S. Wats.
Scurf pea	*Psoralea lanceolata* Pursch
Self heal	*Prunella vulgaris L.*
Sweet coltsfoot	*Petasites palmatus* (Ait.) A. Gray.
Twin flower	*Linnea borealis* L.
Velvet leaf	*Abutilon theophrasti* Medik.
Western sea blite	*Suaeda calceoliformis* (Hook.) Moq.
Wild red raspberry	*Rubus idaeus* L.
Wild strawberry	*Fragaria virginiana* Duchesne
Trees, Shrubs	
Alder, red	Alnus rubra L.
Aspen, trembling	*Populus tremuloides* Michx.
Cranberry, low bush	*Viburnum edule* (Michx.) Raf.
Dogwood, red osier	*Cornus stolonifera* Michx.
Fir, balsam	*Abies balsamea* (L.) Mill.
Larch, siberian	*Larix siberica* L.
Maple, red	*Acer rubrum* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, lodgepole	*Pinus contorta* Loudon

Table 1. List of plant species cited in the report (continued).

Common Name	Scientific Name
Spruce, black	*Picea mariana* (Mill.) BSP.
Spruce, white	*Picea glauca* (Moench) Voss
Tamarack	*Larix laricina* (Du Roi) K. Koch
Moss	
Big red stem	*Pleurozium schreberi* (Brid.) Mitt.
Feather moss	*Hylocomium splendens* (Hedw.) B.S.G.
Hair cap moss	*Dicranum undulatum* Brid.
Knights' plume	*Ptillium crista-castrensis* (Hedw.) De Not.
Recurved sphagnum	*Sphagnum recurvatum* Warnst.