REPORT # ESD/LM/00-2

ACCEPTABLE SALINITY, SODICITY AND pH VALUES FOR BOREAL FOREST RECLAMATION

Alberta
ENVIRONMENT

Acceptable Salinity, Sodicity and pH Values for Boreal Forest Reclamation

Darlene Howat, M.Sc.

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DISCLAIMER

The information contained in this report is intended to provide information on soil salinity, sodicity and pH tolerances of various plant species that may be used for reclamation and how their individual tolerances relate to the values stated in Soil Quality Criteria Relative to Disturbance and Reclamation (Revised) (Macyk et al. 1993) and Land Capability Classification for Forest Ecosystems in the Oil Sands Region (Revised) (Leskiw 1998). Some plant species referred to are native to the boreal forest, others are introduced or non-native species. They have been included to provide the reader with an appreciation of the type and scope of the research that has been conducted thus far on plant species' tolerances for saline and/or sodic soils and soils with pH values that deviate from the typical, undisturbed boreal forest environment. The plant species presented in this manual are not endorsed for use in reclamation in the boreal forest by Alberta Environment or the author.

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ABSTRACT

This report examines plant species used in reclamation and their tolerances for soil salinity, sodicity and pH. The information for each species was obtained from a review of the literature and unpublished information conveyed through personal interviews with people conducting research in this area or working in reclamation. The objective of this report is to determine if the current values for soil salinity, sodicity and pH outlined in Soil Quality Criteria Relative to Disturbance and Reclamation (Revised) (Macyk et al. 1993) and Land Capability Classification for Forest Ecosystems in the Oil Sands (Revised) (Leskiw 1998) need to be revised to reflect plant species' tolerances for these soil parameters. Information on plant response to soil salinity, sodicity and pH is provided, as well as an overview of the soils in the boreal forest.

The results indicate that the current values used for soil salinity, sodicity and pH should not be changed at this time. Additional research to determine tolerances is required for all species and the work should ideally be conducted in the field and for several years, especially for woody species. As well, additional inventories of plant species in undisturbed saline boreal areas would be beneficial, although there are few naturally saline areas in the boreal forest.

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PART I

1.0 INTRODUCTION

1.1 Purpose of the Document

The current limits for salinity, sodicity and pH in reclamation in the boreal forest are stated in two publications: Soil Quality Criteria Relative to Disturbance and Reclamation (Revised) (Macyk et al. 1993) and Land Capability Classification for Forest Ecosystems in the Oil Sands (Revised) (Leskiw 1998). However, boreal plant species' tolerances for salinity, sodicity and pH have not been thoroughly examined and compiled into one document. A few researchers are conducting research in this area primarily due to reclamation efforts in the oil sands region which require plant species for revegetation that have tolerances for higher salinity, sodicity and pH than typically encountered in the undisturbed boreal forest. Therefore, the objective of this report is to determine whether the current limits for salinity, sodicity and pH in boreal forest reclamation can or should be adjusted to reflect plant species' known tolerances.

1.2 Layout of Document

This report is divided into two sections. Part I describes soil salinity, sodicity and pH and plant response to these soil parameters; soils of the boreal forest; the two documents currently used to determine soil quality in reclamation; a summary of the results of the published and unpublished literature review and; a bibliography. Part II provides detailed information on individual plant species categorized by plant type (grass, forb, shrub and tree) and listed alphabetically by Latin name. Values for salinity, sodicity and pH are provided, as well as information on the type of research and plant response.

A significant portion of the information has been gleaned from greenhouse research where variables such as weather, soil variability, competition from weedy species or seeded species, insects, landscape position and other variables have not been a factor. Most plants used in research were seedlings and plant age may play a role in salinity tolerance (Renault and Zwiazek 1997; Croser personal communication, Redfield personal communication; Warner personal communication). For example, seedlings germinating in consolidated tailings may not have the same tolerance as a plant seeded in a peat-mineral mix that eventually roots into saline or sodic overburden. In addition, researchers have observed a large genetic variance for salinity tolerance within members of the same species (Zwiazek personal communication; Croser personal communication; Yeh personal communication; Allen et al. 1994). Therefore, determining specific values for salinity, sodicity and pH may be quite difficult for many species and exceptions to a range of values may be expected.

The salt tolerance of some rangeland grass species is typically derived from crop yield data. However, for the purposes of this report where yield has been provided, it has been used primarily to determine if plant survival occurred.

1.3 Sources of Information

Information for this document has been obtained through a review of the literature and interviews with persons knowledgeable in this area to obtain unpublished information. Specific quantitative values are frequently unavailable for many species as the area of plant physiology relating to boreal species is relatively new. Research has been concentrated on woody species, primarily trees, as investment into commercial forestry in the oil sands region has provided funding into this area. Understory boreal species, especially grasses and forbs, have not been well-researched. In contrast, agricultural and range species have been researched more extensively for salinity and sodicity tolerance. Overall, pH has not been researched for most species (Zwiazek personal communication). Additional sources of generic information on plant tolerances are available in Manual of Plant Species Suitability for Reclamation in Alberta 2nd edition (Hardy BBT 1989), Revegetating with Native Grasses (Wark and Ducks Unlimited Canada 1995), Guideline for Wetland Establishment on Reclaimed Oil Sands Leases (Oil Sands Wetlands Working Group 2000) and A Guide to Using Native Plants on Disturbed Lands (Gerling et al. 1996).

2.0 SOIL SALINITY, SODICITY, pH AND PLANT RESPONSE

Saline or salt-affected soil is becoming more widespread with the presence of oil, gas and oil sands production sites. Brine spills may occur during oil and gas exploration and transport. In slightly more than five years, from 1994 to March 1999, the reported quantity of produced salt water spilled in Alberta was approximately 202,000 m^3 (Alberta Energy and Utilities Board 1999). The chemical composition of brine varies with the associated geologic formation it has contacted. Brine from the Viking Formation near Swan Hills has an EC of 60 dS/m and 24,000 mg/L of chloride, 13,100 mg/L of sodium and a pH of 7.03 (Webster and Innes 1981). Brine water from an oil battery may be more concentrated and have an EC of 187 dS/m, 125,000 mg/L of chloride, 47,250 mg/L of sodium and a total salinity of 201,567 mg/L (Alberta Environmental Centre et al. 1996). (For additional values for salinity and sodicity, please refer to Table 1.) In the oil sands near Fort McMurray, Alberta, a predominant substrate for reclamation and revegetation is saline consolidated/composite tailings (CT)[1], formed by adding gypsum to a mixture of mature fine tails and regular tailings sand (Oil Sands Wetlands Working Group 2000). Determining a plant species' salt tolerance is critical for reclamation and revegetation in the oil sands and where brine spills have occurred.

[1] Throughout this report CT is used to represent both consolidated (Suncor) and composite tailings (Syncrude) material.

Table 1. Values for salinity and sodicity

Source	EC (dS/m)	SAR
Suncor CT Water[1]	0.98 to 1.68	NA
Syncrude CT Water[2]	<1 to 7.9	NA
Brine from Swan Hills Field[3]	60	NA
Brine from Oil Battery[4]	187	NA
KCl Drilling Mud (3 sites)[5]	6.2 to 37.2	35.7 to 111.2
Dispersed Water/Gel Drilling Mud (3 sites)[5]	1.2 to 2.0	3.8 to 18.2
Flocculated Water/Gel Drilling Mud (4 sites)[5]	1.5 to 3.2	10.0 to 37.9
NaCl Drilling Mud (average 9 sites)[6]	39	NA
<u>Soil and Overburden</u>		
Undisturbed Soils near Syncrude: 10 cm mineral horizon[7]	0.06 to 0.33	0.2 to 1.9
Undisturbed Soils near Syncrude: Surface organic layers[7]	0.32 to 1.03	0.2 to 1.9
Clearwater Overburden[8]	4 to 11	NA
<u>Criteria/Guidelines</u>		
Alberta Tier I Criteria[9]	2	6
Soil Quality Criteria-Northern Forest Region, Good Rating[10]	< 2	< 4
CCME Agricultural Soil Criteria[11]	2	5
CCME Commercial Soil Criteria[11]	4	12

NA: Not Available

[1]Nix (1983).

[2]Renault and Zwiazek (1997).

[3]Webster and Innes (1981).

[4]Canadian Association of Petroleum Producers (1996).

[5]Canadian Petroleum Association (1980).

[6]Macyk et al. 1992; Can-Ag Enterprises Ltd. (1986)

[7]Undisturbed soils Macyk and Turchenek (1995) pH values obtained using water.

[8]Qualizza (personal communication).

[9]Alberta Environmental Protection (1994).

[10]Macyk et al. (1993).

[11]Canadian Council of Ministers of the Environment (1999).

Salt tolerance is often measured by plant growth or yield (Shannon 1985). Other factors indicating plant salinity tolerance are germination rates (Hayward and Bernstein 1958) and changes in net photosynthesis, water status or stomatal conductance (Land 1974; Pezeshki and Chambers 1986). Significant factors interacting with salinity that may alter plant growth are humidity, ontogeny, temperature, light, soil fertility, irrigation practices and air pollution (Shannon 1979). Salinity tolerance may be affected by soil calcium concentrations (Rengel 1992, Maas 1993) and in greenhouse research, choice of potting medium (Townsend 1984).

The pH of forest soils frequently increases when surface and sub-surface soils containing calcareous parent geologic materials are admixed. Increased salinity through additions of sodium, possibly from parent geologic materials, brine spills or CT water, can also increase soil pH. With an increase in pH from an acid or neutral soil to an alkaline soil, the availability of some nutrients changes (Marschner 1986). In saline soils, the effect of higher pH is difficult to isolate from the effects of salts (Zwiazek personal communication). Research on the ability of forest vegetation to grow in non-saline neutral or alkaline soils has not been conducted (Zwiazek personal communication).

2.1 Plant Growth and Soil Salinity and Sodicity

Compared to annual crop and horticultural species, there is little information on the mechanisms of salt tolerance in trees of the temperate and boreal forests (Renault et al. 1999). Generally, plant growth becomes affected by the presence of sodium and/or salts when the sodium adsorption ratio (SAR)[2] and electrical conductivity (EC) levels exceed critical values of 15 and 4 dS/m, respectively (Marschner 1986). However, some plant species are sensitive to salinity at less than 4 dS/m. Redfield's (personal communication) research on salinity tolerance of black spruce indicates damage would be predictable above 4 dS/m. In addition to electrical conductivity as an indicator of soil salinity, another criterion can also be used: if soluble salts are present in sufficient quantities to affect plant growth, then the soil is considered saline (Marschner 1986). Electrical conductivity is generally an insufficient indicator of plant growth in saline soils since the actual concentration at the root surface can be much higher than in the bulk soil and because EC characterizes only the total salt content and not its composition (Marschner 1986).

In the oil sands, consolidated tailings water (CT water) contains elevated concentrations of sodium, sulfate, bicarbonate and chloride (Renault et al. 1999). These concentrations may be sufficient to cause phytotoxic effects in plant species (Renault et al. 1999). In addition, the combination of sodium, magnesium and calcium with sulfates and carbonates can raise the pH to alkaline (pH 8 to 10) (Larcher 1980) which can also inhibit plant growth.

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[2] The sodium adsorption ratio describes a relationship between the relative amount of sodium ions in solution to the ratio of calcium and magnesium ions. Specifically, it is the quantity of sodium ions divided by the square root of the sum of calcium ions plus magnesium ions (for concentrations in mmoles/L) (Dudas and Luther 2000).

2.2 Salt Tolerance

Salt tolerance is defined as the ability of a plant to grow and complete its life cycle on saline substrates that contain high concentrations of salt, mostly NaCl, but sometimes also other salts including calcium salts and sulphates (Jeschke 1984). Plant tolerance for saline environmental conditions does not imply the particular species has a physiological requirement for the conditions to survive and reproduce (Grubb 1985). However, tolerance for the extreme or unusual environmental condition is important as plants require the conditions they are normally associated with in their native environment to attain maximum growth rates. Phenological features of plants grown in saline soils includes a smaller stature, with darker, more bluish foliage and occasionally brown leaf tips, leaf mottling, leaf curling and/or chlorosis. A high chlorophyll content and thicker cuticle produces the bluish colour (Black 1968).

Plants with salt tolerance can endure the toxic and osmotic effects of increased ion concentration caused by the presence of excess salts (especially Na^+, Cl^- and SO_4^{-2}) without serious impairment of vital function (Larcher 1980). This will depend on the plant species, tissue type and level of vitality (Larcher 1980). Salt tolerance may involve avoidance or the ability to keep the salts away from parts of the plant where they are harmful (Allen et al. 1994). For example, in woody species exclusion of sodium or especially chlorine ions from plant roots or shoots is the most important mechanism for salt tissue tolerance (Allen et al. 1994). Species with salt tolerant protoplasts can survive 4% to 8% NaCl, whereas salt-sensitive protoplasts are destroyed in solutions of 1.0% to 1.5% NaCl (Larcher 1980).

Although sodium chloride is commonly used in research, different salt combinations may produce significantly different effects for salt tolerance (Banuls and Primo-Millo 1992). Research conducted by Franklin (personal communication) indicated that NaCl (60 mMol, 6 dS/m) caused greater reductions in the growth of 1 year old jack pine seedlings and more tissue damage compared to $NaSO_4$ (60 mMol, 10.5 dS/m) during a 10 week exposure. These salts, NaCl and $NaSO_4$, are common in Alberta. The difference in mortality between the treatments was not significant. A tissue analysis indicated nutrient deficiency did not occur in either treatment. Chloride is believed to cause disorganization in membranes and lead to electrolyte leakage. As a result of exposure to NaCl, jack pine seedlings may have experienced increased membrane permeability and increased ion uptake. Franklin (personal communication) believes the ionic effect in jack pine is more important than SAR or EC.

Zwiazek (personal communication) discovered that salt tolerance in woody boreal species involves a limited transfer of sodium to plant shoots, while chloride transfers readily to shoots. Therefore, chloride is believed to be more toxic to woody species than sodium and related to chlorosis (Zwiazek personal communication).

2.3 Mechanisms of Salt Tolerance

The adaptability of a species to a saline environment requires it have "key characters" that allow the plant to survive in the presence of competitors (Grubb 1985). To grow in a saline soil with a high salt concentration, a plant must have at least one of these key characters to ensure survival: salt-sequestration in vacuoles, salt-exclusion at the roots or salt-secretion via glands or via evanescent, inflated leaf hairs (Grubb 1985). Halophytes are able to eliminate excess salts by shedding plant parts heavily loaded with salt (Larcher 1980). For example, *Atriplex* and *Halimione* are able to collect chloride in vesicular hairs that die off and are replaced (Larcher 1980). Other halophytes may have glands in the leaves and hair that are able to excrete salt to keep accumulations to tolerable limits (Larcher 1980). In some species, leaf abscission or leaf fall may occur in older leaves that have accumulated considerable quantities of salt. Shortly afterwards, new leaves appear and continue to accumulate salts (Larcher 1980).

The mechanisms by which salts damage plants is poorly understood. Salts may affect plants by lowering water availability, causing toxicity, or influencing plant energy relations (Allen et al. 1994). Understanding how these mechanisms damage plants may lead to a more comprehensive understanding of salt tolerant species. Current knowledge of salt tolerance indicates it may be achieved through salt exclusion or tissue tolerance. Each of these mechanisms is described below.

2.3.1 Soil salinity and plant water availability

Plant dehydration is an indirect effect of soil salinity. As the salt concentration in soil water increases, less water is available to plants as the high concentration of salts produces high osmotic pressure. If a plant can produce an osmotic potential lower than that of the soil solution, it can obtain water from the soil (Larcher 1980). Nutrient uptake is also decreased as water availability decreases. Therefore, drought and nutrient stress can occur simultaneously (Allen et al. 1994). Halophytes compensate for the low osmotic potential in saline soil by accumulating salt in their cell sap (Larcher 1980).

The osmotic potential of mesophytes, xerophytes and halophytes was observed to be directly related to salinity and inversely related to the soil-moisture level with soil salinity the most decisive factor (Hayward and Bernstein 1958). Hayward and Bernstein (1958) used two halophytes (*Salicornia*, *Salsola*) and a number of crop species to determine a wilting coefficient. For most of the crop species, the wilting coefficient of the saline soils varied, depending on the plant species. In addition, the soil available moisture content decreased as the salinity increased. However, the wilting coefficient of halophytes was constant or lowered with increased salinity.

2.3.2 Soil salinity and plant toxicity

Plant growth is directly affected by high levels of sodium chloride and other salts. The absorption of salt requires osmotic adjustment but can result in ion toxicity and nutrient imbalances (Marschner 1986). Excess sodium and more importantly chloride has the potential to affect plant enzymes and cause cell swelling, resulting in reduced energy production and other physiological changes (Larcher 1980). In addition, high concentrations of sodium chloride reduces the uptake of important mineral nutrients, K^+ and Ca^{2+}, which further reduces cell growth especially for roots (Larcher 1980). In woody species, salt damage includes late, stunted buds, small leaves and necroses in buds, roots, leaf margins and shoot tips. Before the growing season ends, leaves become yellow and dry and root and shoot sectors die (Larcher

1980). Greenway and Munns (1980) found growth of woody species was reduced by concentrations of soil water chloride that were too low to cause water deficits.

2.3.3 Soil salinity and plant energy relations

Plants growing in saline soils may experience changes in energy relations as a result of translocation of carbohydrates and reduced ATP production. Energy from photosynthates may also be diverted from growth to osmoregulation or used for maintenance of respiration or ion transport (Pasternak 1987).

2.3.4 Salt exclusion

The ability to exclude sodium or especially chloride ions from the tissue of roots or shoots is the most important mechanism operating in salt tolerant woody species (Allen et al. 1994). For species not adapted to salt exclusion, excluding the salt ions at the cell membrane will minimize toxicity but expedite water deficits (Marschner 1986). Assessment of the relative contribution of ion toxicity versus water deficit to the inhibition of growth is impossible when salt concentrations are high (Marschner 1986). If saline conditions have increased soil pH, then salt ion exclusion may also lead to nutrient deficiencies as nutrient availability decreases with increased pH and nutrient ions are excluded (Zwiazek personal communication).

2.3.5 Salt tissue tolerance

Salts are not excluded from the plant if it has developed salt tissue tolerance. Salt ions are stored in vacuoles and osmoregulation in the cytoplasm is altered to accommodate the salts (Greenway and Munns 1980). Sequestering salts in plant tissues keeps salts away from parts of the plant where they are harmful (Allen et al. 1994). In species that are not adapted to saline soils, low concentrations of salinity can cause growth inhibition due to ion toxicity (Marschner 1986). In trees, storage of chloride ions in vacuoles of ray cells and in the lumen and cells walls of tracheids has been observed. These areas are presumed to be less sensitive to chloride ions (Foster and Sands 1977).

2.4 Considerations for Salt and Sodicity Tolerance

It is important to note that several factors beyond specific EC or SAR values will influence salt and sodicity tolerance. For example, there is little information on intraspecific genetic variation in salt tolerance of forest trees (Allen et al. 1994). Salt and sodicity tolerance may vary considerably with genetic traits (Yeh personal communication; Zwiazek personal communication; McKenzie personal communication). For example, some plant species may accumulate salts thereby phytoremediating the area for members of the same species that have less salt tolerance (Yeh personal communication). Some members of a species may be able to exclude salt ions (Yeh personal communication). By finding the gene that controls salt exclusion or tolerance and isolating it in native woody species, reforestation in saline soils may be a possibility (Yeh personal communication).

A sudden change in salinity may induce salt shock (Edwards and Blauel 1975). Changes in salinity may be due to a brine spill or in an experiment where seedlings are subjected to saline conditions following germination in a non-saline growth medium. A plant species' tolerance for salinity will be overridden by a sudden exposure to salinity, even if the species is a halophyte (Repp 1958). Thomson (1988) indicated that different adaptive mechanisms may be involved in gradual acclimation to salinity in contrast to adjustment to a sudden shock.

The sensitivity to salinity of a given species may change during ontogeny (Marschner 1986). Salinity tolerances may increase or decrease depending on the plant species and/or environmental factors. For some species, salt sensitivity may be greatest at germination, whereas for other species, sensitivity may increase during reproduction (Marschner 1986). Hayward and Bernstein (1958) determined the correlation of salt tolerance in germination to salt tolerance at later growth stages is poor for many crop species. Differences in juvenile and mature plant responses to salinity and salt tolerance are unknown for forest species and need to be investigated (Townsend 1989). Franklin (personal communication) conducted research on jack pine germination and establishment and found that 30 day old seedlings experienced higher mortality when exposed to NaCl (60 mMol, 6 dS/m) and $NaSO_4$ (60 mMol, 10.5 dS/M) compared to 1 year old seedlings. The difference in survival may be attributed to an osmotic effect as at 30 days old the seedlings are unlikely to stop transpiration whereas at 1 year old they may have more control over transpiration (Franklin personal communication).

2.5 Physical Properties of Saline and Sodic Soils

Sodic soils have a SAR of 15 or greater. The quantity of exchangeable Na^+ in sodic soils is sufficient to interfere with plant physiology and will affect the physical and chemical properties of the soil which decreases its suitability for plant growth (Black 1968). High concentrations of sodium combined with low concentrations of salts, cause soil aggregates to break down, reducing pore size, increasing bulk density and decreasing total porosity (Tisdale et al. 1993). When wet, dispersion of soil occurs due to the excess sodium ions which cannot bind the soil particles together into stable aggregates, causing puddling or slickspots. Sodium ions are hydrated and have a layer of water surrounding them that prevents tight adsorption to clay particles or aggregation between particles. When dry, a hard crust forms on the soil surface, causing poor aeration and inhibiting or preventing germination and/or emergence of seedlings (Hayward and Bernstein 1958). Detrimental effects of sodium vary with the soil and plant characteristics (Black 1968).

Sodium concentrations will influence the structure of saline soils. For example, saline-sodic soils are highly aggregated. The salts compete for water with sodium and decrease the water layer around the sodium ion, causing flocculation. In contrast, without sodium, soil structure is not affected by salinity. The main characteristic of a saline soil is the limited plant available water caused by ions dissolved in the soil solution (Hausenbuiller 1985).

In an undisturbed saline soil, surface layers of soil accumulate salts as evaporation and capillary rise occurs. Seed placement near the soil surface is within an area of salinity that is substantially greater than the average salt content in the top 10 to 20 cm of the soil surface. Moreover, the evaporation of moisture at the soil surface increases the osmotic pressure and moisture tension in that zone. The increased moisture tension amplifies the effect of the salinity at germination (Hayward and Bernstein 1958).

Within a landscape, salts move locally or regionally with groundwater flows and can be discharged onto or near the soil surface. Salts in groundwater in Alberta originate from marine bedrock that may be incorporated into glacial till. In groundwater recharge areas, excess surficial water percolates into groundwater and depending on the depth of groundwater flow, passes through a saline glacial aquifer or over impermeable marine bedrock acquiring salts. If the saline water discharges into areas with high evaporation and low precipitation, salts will accumulate on the soil surface as the precipitation will be insufficient to leach them downward (Dudas and Luther 2000).

In the oil sands, saline discharge may occur within the rolling topography sculpted out of CT and saline overburden. Depressional areas and plateaus formed from existing berms may act as recharge areas. The volume of discharge water will depend on the recharge and groundwater flow rates and salinity concentrations will vary with overburden and CT heterogeneity. During the wettest months of July and secondarily June (Strong and Leggat 1992) salt deposits formed at discharge areas may be leached downward. At Syncrude, landscapes can be engineered to have salts leached out of the surface to some extent but saline discharge may still occur in some areas (Qualizza personal communication). Gypsum (calcium carbonate) is typically used in agricultural soils to ameliorate salinity, but if used as an amendment for overburden and CT, it will be counter productive as the addition of calcium will increase salinity.

2.6 Soil pH

The pH of a soil influences several soil characteristics: weathering processes, soil structure, humification, biotic activity, mobilization of nutrients and ion exchange. Soil pH changes seasonally with the distribution of precipitation and accurate characterization of pH therefore must therefore be measured over a full year in the zone penetrated by roots (Larcher 1980). For pH values of some sources, soils of the boreal and for criteria and guidelines, see Table 2.

Table 2. Values for pH

Source	pH
Suncor CT Water[1]	7.8 to 8.4
Syncrude CT Water[2]	5.26 to 8.41
Brine from Swan Hills Field[3]	7.03
KCl Drilling Mud (3 sites)[4]	8.0 to 8.5
Dispersed Water/Gel Drilling Mud (3 sites)[4]	8.1 to 8.8
Flocculated Water/Gel Drilling Mud (4 sites)[4]	8.0 to 9.3
NaCl Drilling Mud (average 9 sites)[5]	7.61
Rain Water[6]	5.6 to 5.9

Soil and Overburden	
Undisturbed Soils near Syncrude: 10 cm mineral horizon[7]	4.8 to 6.0
Mesic peat[7]	5.4 to 7.5
Fibric peat[7]	3.6 to 4.2
Criteria/Guidelines	
Alberta Tier I Criteria[8]	6.5 to 8.5
Soil Quality Criteria-Northern Forest Region, Good Rating[9]	5.0 to 6.5
CCME Agricultural Soil Criteria[10]	6 to 8
CCME Commercial Soil Criteria[10]	6 to 8
CCME Water Quality Guidelines for Protection of Aquatic Life-Freshwater[10]	6.5 to 9.0
CCME Water Quality Guidelines for Protection of Aquatic Life-Marine Water[10]	7.0 to 8.7

[1]Nix (1983).
[2]Renault and Zwiazek (1997).
[3]Webster and Innes (1981).
[4]Canadian Petroleum Association (1980).
[5]Macyk et al. 1992; Can-Ag Enterprises Ltd. (1986)
[6]Kaufman and Franz (1993).
[7]Undisturbed soils Macyk and Turchenek (1995) pH values obtained using water.
[8]Alberta Environmental Protection (1994).
[9]Macyk et al. (1993).
[10]Canadian Council of Ministers of the Environment (1999).

2.6.1 Plant growth and pH

Soil pH is an important factor in plant growth. Viability of plants is directly affected by soil pH in addition to the nutrient availability. The protoplasm of plant root cells is severely damaged below pH 3 and above pH 9 (Larcher 1980). Increased concentrations of Al^{3+} in very acid soils and borates in alkaline soils are poisonous to roots (Larcher 1980). Tolerance to soil pH varies by plant species (Larcher 1980). Most vascular plants have a broad optimum range between weak acidity and weak alkalinity, and are able to exist between pH 3.5 and 8.5 (Larcher 1980). Some plants that are native to calcareous soils (pH 7 to 8), are able to grow larger on soils with pH 5 to 6, but not all species exhibit this growth response (Grubb 1985). Two species with an equal tolerance are not necessarily the most abundant in the same fraction of their tolerance range. One species may have a maximum tolerance for pH 4 to 6, while another may have maxima at pH 3 to 4 (Grubb 1985).

Zwiazek (personal communication) believes that pH should be researched further as it could be very important for plant growth. Plant absorption of ions from the soil to obtain essential nutrients could result in a nutrient deficiency with an increase in pH due to increased alkalinity, as some ions could be unavailable at a higher pH. If a plant is practicing salt exclusion, deficiencies in essential nutrients could occur (Zwiazek personal communication).

In an experiment with *Plantago major* and *P. lanceolata*, the range of pH values in each species' habitat was analyzed (Van Der Aart 1985). Within the 72 habitats where *P. lanceolata* was found, the soil pH varied from 4.3 to 7.8 (Van Der Aart 1985). *P. major* was discovered in 17 habitats where soil pH values were 5.3 to 8.4. Occupation of a wide range of pH values is evident for both species, indicating pH is not a limiting factor for growth in most cases (Van Der Aart 1985). Plants of a different species may not have the same range of adaptability and may require a narrow range of pH values to survive (Grubb 1985).

2.6.2 Acidic soils

The pH of a soil is important to plant development as the availability of some nutrients is affected by pH. Soils with pH lower than 6.5 are generally considered to be acidic, due to the acidifying properties of organic matter, aluminum, carbon dioxide and presence of very low quantities of clay minerals (Tisdale et al. 1993). Changes in soil pH can be buffered by organic matter and clay minerals and therefore, coarse-textured soils or those with low organic matter do not have the same ability to maintain a constant pH and are usually acidic. The degree of acidification by soil organic matter or humus will vary with the type of vegetation, as coniferous vegetation has a lower pH than deciduous.

Acidification is controlled by the carboxylic and phenolic reactive groups, within soil organic matter and humus, behaving as weak acids and dissociating, releasing hydrogen ions. Soluble salts are derived from organic matter decomposition, mineral weathering or manure. In acid soils, the cations of these salts will displace Al^{3+} and decrease the pH further. Aluminum is a common component of most soils with many multivalent forms and divalent metal cations will reduce soil pH more readily than monovalent metal cations (Marschner 1986).

The high concentration of H^+ ions is not the limiting factor to plant growth, but rather the toxicity of other nutrients at low pH values and/or the deficiency in essential nutrients that occurs as a result of acid soils (Marschner 1986). Large quantities of aluminum, iron and manganese ions are liberated at low pH values and are toxic to the majority of plant species (Larcher 1980). The nutrients Ca^{2+}, Mg^{2+}, K^+, PO_4^{3-} and MoO^{2-} are depleted or unavailable in a form useable to plants when a soil is very acid (Larcher 1980). Reduced plant available nitrogen can be prevalent in acidic soils due to leaching. Total and available nitrogen is very low in strongly acid soils and the available nitrogen is limited to NH_4^+ since nitrification is inhibited (Marschner 1986). In some instances, low levels of sulphur, potassium, molybdenum, copper and zinc may also occur (Marschner 1986). Since many of the macro and micronutrients are found at low concentrations in acid soils, soil fertility is considered low (Marschner 1986).

2.6.3 Alkaline soils

Alkaline soils have a pH greater than 7, due to the presence of calcium carbonate from a calcareous parent geological material. Calcium carbonate buffers the pH to 7.5 to 8.5 (Marschner 1986). When pH is greater than 8, soils are sodic or alkali and have a SAR of 15 or more.

Sodic soils have nutrient limitations and are deficient in zinc, iron, phosphorus and occasionally calcium, potassium and magnesium (Marschner 1986). Zinc deficiency in alkaline soil has been well documented with many crop species and some species develop severe symptoms at pH 8.2, whereas for other species the symptoms are lacking (Marschner 1986). However, nitrogen is the most limiting nutrient when soils are alkaline. In sodic soils, boron may be at phytotoxic concentrations due to negligible leaching (Marschner 1986).

Alkaline soils may be iron deficient, leading to lime-induced chlorosis in plants. High bicarbonate concentrations in the soil are mainly responsible for iron deficiency that is further increased by high soil moisture or anaerobic conditions (Marschner 1986). The method by which high bicarbonate levels induce chlorosis is not fully understood (Marschner 1986). Plant adaptation to these deficiencies is known to occur for agricultural crops. For example, Marschner (1986) states there are impressive differences in the iron efficiency of different species as well as cultivars within a species. There are mechanisms of root response to iron deficiency and resistance to lime-induced chlorosis which differ among plant species (Marschner 1986).

In low rainfall areas with alkaline soils, low soil moisture and water deficits in plants are constraints to growth (Marschner 1986). Phosphorus and potassium uptake by plants is dependent upon diffusion, so low soil moisture impairs the ability of the roots to obtain these nutrients. Labile phosphorus may be limiting, so reduced soil moisture increases the severity of the problem (Marschner 1986).

3.0 SOILS OF THE BOREAL FOREST

Gray Luvisolic and Organic soils are the most areally-extensive soil groups found in the boreal forest region according to Shields and Lindsay (1988). Solonetzic and alkaline soils are found to a lesser extent in the region.

3.1 Luvisolic Soils

Luvisolic soils are developed in the cooler boreal regions in association with deciduous, coniferous and mixed forest vegetation and forest-grassland transition areas (Clayton et al. 1977). They are located on well drained sites and are generally formed from glacial till parent geological material, but occasionally from fluviolacustrine or fluvioglacial deposits (Alberta Environmental Protection 1998). Typical Luvisols have an organic LFH horizon on top of a shallow Ah and/or Ahe horizon with a loam to clay loam topsoil texture (Fedkenheuer et al. 1999). The Ah/Ahe contains humus from the decomposition of the LFH layer and minerals. Below the Ah/Ahe horizon is an Ae, Bt, possibly a BC and Ck horizon containing free carbonates (Fedkenheuer et al. 1999). The diagnostic Bt horizon is caused by clay translocation (eluviation) from the Ae, causing the Ae to have a light colored, platy structure (Hausenbuiller 1985). In relation to the other horizons, the Ae also has a low moisture content, very little organic matter and is acidic (Fedkenheuer et al. 1999). Clay, iron, aluminum and organic carbon accumulate in the often acidic Bt horizon (Fedkenheuer et al. 1999). Its structure is weak to blocky and the high clay content results in a reduced permeability when dry

(Fedkenheuer et al. 1999). The B and C horizons typically have a high base status (Hausenbuiller 1985). On average, the calcareous Ck horizon is 1.2 m or more below the surface (Bentley et al. 1971) and has a neutral to basic pH (Fedkenheuer et al. 1999).

3.2 Organic Soils and Other Mineral Soils

Organic soils are located in wetland environments in poorly drained lowland sites and on upland plateaux and are normally associated with peat (Alberta Environmental Protection 1998). Anaerobic conditions and low temperatures make the rate of decay slower than the rate of organic matter deposition that produces organic soils (Hausenbuiller 1985). To be classified as an organic soil, more than 17% of a soil layer should be organic carbon (Hausenbuiller 1985) with more than 30 cm of peat. The organic fraction is the prime factor in determining soil properties although the soils may have organic mineral deposits (Hausenbuiller 1985).

Other mineral soils that are found less frequently in the boreal forest are Dystric and Eutric Brunisols, Gleysols, Regosols, Gray Solonetzics and Black Chernozemic soils (Alberta Environmental Protection 1998).

3.3 Solonetzic Soils

Solonetzic soils, known as the Joslyn series, have been surveyed west of Fort McMurray, in association with Orthic Gray Luvisols (Alberta Environment 1982). Generally, saline soils are not found in the boreal forest with the exception of some saline discharge areas (Lieffers personal communications) and most salts would be leached out of the rooting zone over time with the amount of precipitation in the boreal (Lieffers personal communication; Macyk personal communication). Saline soils in undisturbed areas are uncommon throughout most of the boreal forest (Leskiw personal communication; Turchenek personal communication; McKenzie personal communication; Lieffers personal communication; Purdy personal communication). The association of pedogenic salts and forests is largely restricted to northern latitudes where both low precipitation and moderate potential evapotranspiration occur simultaneously (Viereck et al. 1993).

In Canada, saline soils occur in drier, southerly regions of the Prairie provinces where potential evapotranspiration exceeds precipitation (McKell et al. 1986). Precipitation in northern Alberta's mid boreal mixedwood ecoregion is 397 mm per year (mean) and ranges between 155 to 345 mm per year in the summer and 38 to 93 mm in the winter (Strong and Leggat 1992). The climate summer moisture deficit ranges from a minimum of –276 mm to a maximum of –55 mm (Strong and Leggat 1992). This area is classed as humid based on the quantity of precipitation, potential evaporation, irradiation, length of growing season and mean annual temperature (Larcher 1980). As a result, pedogenic salts would be leached downward through the soil. Surficial salts may occur naturally in areas where saline groundwater percolates to the surface (Burchill and Kenkel 1991). Saline springs appear to be rare and isolated in the boreal forest and occur mainly along the Slave and Athabasca Rivers in northeastern Alberta (Pearson 1963).

Macyk (personal communication) believes areas north of Fort Vermilion have elevated SAR and possibly higher EC values than most of the boreal. However, the fine textured soils of the area may be more responsible for the stunted poplar rather than elevated SAR or EC. Turchenek (personal communication) thinks the short and stunted aspen and other boreal upland species growing in the Joslyn Solonetzic soils may be have more influenced by soil moisture regimes. The Joslyn soils were located in depressional areas, possibly part of a regional discharge network flowing towards the Athabasca River (Turchenek personal communication). The clayey soil tended to have pseudo gleying occurring between the Ae and Bnt horizons indicating the soils are periodically anaerobic (Turchenek personal communication).

3.4 Alkaline Soils

Alkaline boreal forest soils are located in the Hinton area caused by calcareous loess material blown in from the Athabasca Valley (Archibald personal communication). Tree seedling establishment has not been successful in this area (Macyk personal communication).

3.5 Soils Associated with Syncrude's Lease 17

The soils on Syncrude's Lease 17 are primarily Gray Luvisols and Organics although Brunisols and Gleysols are also present (Syncrude Canada 1973). Some Organic soils have more than 300 cm of peat, but the average is 90 to 120 cm (Syncrude Canada 1973). Approximately thirty per cent of Lease 17 lies within the bog-muskeg zone (Syncrude Canada 1973). Solonetzic soils generally do not occur in this area, except in isolated localities (Syncrude Canada 1973).

3.6 Considerations for Reclamation in Saline and Alkaline Areas

Soil texture determines water holding capacity and is a more important factor than SAR or EC in reclamation in the oil sands (Macyk personal communication). When the bermed areas are capped, there may be lateral outward saline discharge along with an upward movement depending on the precipitation regime (Macyk personal communication). The depth of capping material will not provide a buffer from salinity (Macyk personal communication). Reclaimed areas in the bison pasture at Syncrude were either not capped or capped with a fine textured soil mixed with peat to a 20 cm depth (Macyk personal communication). Vegetation establishment rates were different due to the soil physical characteristics and not soil chemical properties (Macyk personal communication).

During dry conditions, following establishment in a capping medium, trees may root into tailings looking for soil water and are likely stressed due to drought, not the chemistry of the tailings (Macyk personal communication). Physical characteristics are frequently more consequential for plant growth compared to soil chemistry (Macyk personal communication). Redfield's (personal communication) research indicates drought tolerance is indicative of salt tolerance, but salt tolerance will not enable drought tolerance. The effect SAR has on soil physical properties may necessitate the need for different SAR limits for individual soil textures (Qualizza personal communication).

Capping soil used in reclamation at a Grande Cache, Alberta mine had a high pH due to admixing with calcareous overburden, but did not influence the growth of lodgepole pine (Macyk personal communication). Attributing a single factor to successful plant establishment or mortality is difficult in a reclaimed area where many factors are present to influence plant growth (Macyk personal communication). Macyk (personal communication) believes pH did not influence productivity as the 40 to 50 grass species and alfalfa at Grande Cache established well and continued to thrive. McKenzie (personal communication) thinks pH is not usually a problem for plant growth; most species can tolerate a lot of variation in pH. In the oil sands, Macyk (personal communication) has observed little change in pH over time and more variation seasonally. The vegetation used in reclamation research did not appear to be impacted by pH (Macyk personal communication).

3.7 Other Factors That May Influence Plant Establishment in the Boreal Forest

In reclaimed areas, especially on south-facing slopes, soil temperatures can rise dramatically. Croser (personal communication) believes reclamation research involving woody species at Syncrude was influenced by soil temperature. Deciduous species grew each year of the research, but looked poor at the end of the season. In contrast, the coniferous species died after 1 or 2 years. The conifer roots were not as large and extensive as the deciduous roots and therefore did not extend as deeply into the soil and may have baked.

Redfield (personal communication) indicated that NaCl in conifer heartwood may leach out eventually and cause mortality. This process could lead to mortality of mature coniferous trees in reclaimed saline areas.

In the oil sands, soil oxygen deficiency may be an important issue. In dry tailings, the degradation of residual hydrocarbons produces methane that displaces oxygen from the soil (Zwiazek personal communication). If the soil is wet from the CT expressing water, the soil becomes anaerobic and oxygen deficient. Therefore, plants must be able to tolerate oxygen deficiencies in wet and dry soil in oil sands reclamation (Zwiazek personal communication).

Boron is always associated with salt and there are high concentrations of boron in CT (Zwiazek personal communication). Therefore, boron toxicity may be associated with poor salt tolerance as boron is quite toxic to plants when it is found in high concentrations in the soil. Zwiazek (personal communication) thinks there is a need to conduct research on the possible synergistic effects of boron and salt.

4.0 SOIL SALINITY, SODICITY AND pH VALUES FOR LAND CAPABILITY ASSESSMENT

4.1 Soil Quality Criteria Relative to Disturbance and Reclamation

Reclamation and revegetation success depends on soil quality. Criteria for rating soils as good to unsuitable, or equivalent to the pre-disturbed soil have been developed as a predictor for suitability for revegetation. Soil Quality Criteria Relative to Disturbance and Reclamation (Revised) (Macyk et al. 1993) contains criteria for evaluating the suitability of undisturbed and reconstructed soil for all regions of the province, including the Northern Forest Region. The criteria rate soil and overburden materials by using a number of factors including soil physical and chemical properties. In addition, soil nutrients, water holding capacity and plant water availability must be considered. The depth of soil replaced on overburden is not specified in this document, but the authors note that replaced soil thickness should be no more limiting to plant growth than it was in the undisturbed state (Macyk et al. 1993).

4.1.1 Physical and chemical criteria rating system

Ratings for suitability of surface material (upper lift) and subsurface material (lower lift) for revegetation are good, fair, poor and unsuitable. The following is an excerpt from Macyk et al. (1993) describing the physical and chemical criteria rating system.

Evaluations of soil suitability are made by considering the interaction of various soil properties and characteristics to give an overall rating of the degree of soil suitability (Macyk et al. 1993). Three categories of suitability and one category to indicate unsuitable soils are used. The four categories are as follows:

1. **Good (G)** - None to slight soil limitations that affect use as a plant growth medium.

2. **Fair (F)** - Moderate soil limitations that affect use, but can be overcome by proper planning and good management.

3. **Poor (P)** - Severe soil limitations that make use questionable. This does not mean the soil cannot be used, but rather careful planning and very good management is required.

4. **Unsuitable (U)** - Chemical or physical properties of the soil are so severe reclamation would not be economically feasible or in some cases impossible.

4.1.2 Criteria for evaluation of surface and subsurface soil

In the Northern Forest Region, evaluation of surface material and subsurface material for revegetation suitability is determined by the criteria in Tables 3 and 4.

Table 3. Criteria for evaluating the suitability of surface material (upper lift) for revegetation in the Northern Forest Region

Rating/Property	Good (G)	Fair (F)	Poor (P)	Unsuitable (U)
Reaction (pH)[1]	5.0 to 6.5	4.0 to 5.0	3.5 to 4.0	< 3.5 and > 9.0
Salinity (EC)[2] dS/m	< 2	6.5 to 7.5 2 to 4	7.5 to 9.0 4 to 8	> 8
Sodicity (SAR)[2]	< 4	4 to 8	8 to 12	> 12[3]
Saturation (%)[2]	30 to 60	20 to 30 / 60 to 80	15 to 20 / 80 to 120	< 15 and > 120
Stoniness/Rockiness (% Area)[4]	< 30/ < 20	30 to 50 / 20 to 40	50 to 80 / 40 to 70	> 80 / > 70
Texture	FSL, VFSL, L, SiL, SL	CL, SCL, SiCL	LS, SiC, C, HC,	S
Moist Consistency	very friable, friable	loose, firm	very firm	extremely firm
$CaCO_3$ Equivalent (%)	< 2	2 to 20	20 to 70	> 70

[1] pH values presented are most appropriate for trees, primarily conifers. Where reclamation objective is for other end land uses, such as erosion control, and where other plant species may be more important, refer to Table 6 in Macyk et al. (1993).
[2] Limits may vary depending on plant species to be used.
[3] Materials characterized by an SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.
[4] < 25 cm diameter stones/rocks intercepting surface.
From Macyk et al. (1993).

Table 4. Criteria for evaluating the suitability of subsurface material (lower lift) for revegetation in the Northern Forest Region

Rating/Property	Good (G)	Fair (F)	Poor (P)	Unsuitable (U)
Reaction (pH)[1]	5.0 to 7.0[2]	4.0 to 5.0	3.5 to 4.5	3.5 and > 9.0
Salinity (EC)[3] dS/m	< 3	7.0 to 8.0[2]	8.0 to 9.0	
		3 to 5	5 to 8	> 8
Sodicity (SAR)	< 4	4 to 8	8 to 12	> 12[4]
Saturation (%)	30 to 60	20 to 30 60 to 80	15 to 20 80 to 100	< 15 and > 100
Coarse Fragments (%/Vol)	< 30[5] / < 15[6]	30 to 50[5] / 15 to 30[6]	50 to 70[5] / 30 to 50[6]	> 70[5] / > 50[6]
Texture	FS, VFSL, L, SiL, SL	CL, SiC, SiCL	S, LS, SC, C, HC	bedrock
Moist Consistency	very friable, friable, firm	loose, very firm	extremely firm	hard rock
$CaCO_3$ Equivalent (%)	< 5	5 to 20	20 to 70	> 70

[1] pH values presented are most appropriate for trees, primarily conifers. Where reclamation objective is for other end land uses, such as erosion control, and where other plant species may be more important, refer to Table 6 in Macyk et al. (1993).
[2] Higher value takes into consideration that in the lower lift the pH values of the soils are generally higher. Normally the pH rating should not be different from those shown in Tables 9 and 11 in Macyk et al. 1993.
[3] Limit may vary depending on plant species to be used.
[4] Materials characterized by an SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.
[5] Matrix texture (modal) finer than sandy loam.
[6] Matrix texture (modal) sandy loam and coarser.
From Macyk et al. (1993).

The criteria are used to develop an overall rating for each horizon or layer (Macyk et al. 1993). The most limiting property or rating becomes the ultimate rating for each horizon or soil layer. Interrelated parameters such as sodicity, saturation percentage and texture can determine the overall rating for that horizon. For example, if the rating was fair for each of these parameters and for the remaining parameters the ratings were fair or better, then the overall rating would be fair (Macyk et al. 1993).

4.1.3 Salinity, sodicity and pH

Soil salinity, sodicity and pH values are included as criteria to determine suitability for revegetation. However, Macyk et al. (1993) note that the values stated for salinity and sodicity may vary depending on the plant species used in revegetation. Sodicity criteria values must also be considered in context of the soil texture, so if the soil is a sandy loam or coarser, then a SAR of 12 to 20 would be rated as poor instead of unsuitable. The values for pH are most appropriate for trees, primarily conifers (Macyk et al. 1993). However, if other plant species will be used for revegetation in the Northern Forest Region, the soil can be evaluated using criteria presented for evaluating the suitability of topsoil in the Plains Region (Macyk et al. 1993).

4.1.4 Management practices

Macyk et al. (1993) indicate some parameters can be improved or overcome in the ratings by appropriate management practices. For example, stoniness could be overcome by stone picking which would result in a better soil if that was the main limiting factor. However, the document does not contain suggestions as to the extent to which management practice could impact ratings that are developed (Macyk et al. 1993).

4.2 Land Capability Classification for Forest Ecosystems in the Oil Sands

A more recent publication has been written specifically for oil sands reclamation entitled Land Capability Classification for Forest Ecosystems in the Oil Sands (Revised) (Leskiw 1998). The classification manual was developed as a system to be used in the planning process and to evaluate land capability. Reclamation success can be evaluated by a comparison of pre- and post-disturbance capability (Leskiw 1998). The document clearly indicates that determining "equivalent capability" involves a series of choices, including "trade-offs" among classes or components, that is done in the planning process. The ultimate goal is to reconstruct favorable growing conditions in the soil profile, with emphasis on the root zone or upper 1.0 m (Leskiw 1998). The factors that determine root zone quality and are used to classify capability are organic carbon content (OC), available water holding capacity (AWHC), nutrient retention capacity, structure and consistence, surface peat thickness, salinity, sodicity, soil reaction, moisture regimes and nutrient regimes (Leskiw 1998). In terms of the landscape, the main parameters are slope, aspect, position, erosion and stoniness.

4.2.1 Soil capability evaluation classes

The soil capability evaluation applies to the top 1.0 m of soil (root zone) and is closely related to forest productivity (Leskiw 1998). The main plant species considered for productivity are jack pine (*Pinus banksiana*), aspen (*Populus tremuloides*), white spruce (*Picea glauca*) and black spruce (*Picea mariana*). Soil physical and chemical properties that influence the quality of the root zone soil material are measured as soil quality is a predictive measure of site productivity.

Assignment of soil to a particular class infers a corresponding measure of productivity and limitations. Each capability class is related to a number of index points. A 20% reduction in inherent forest productivity is the target used for establishing threshold values between classes of soils (Classes 1 to 5) (Leskiw 1998). For example, a Class 2 soil would be expected to have a 20% lower yield than a Class 1 soil, a Class 3 soil would have a 20% reduction in yield from a Class 2 soil, etc. (Leskiw 1998). Reduction in yield is provided in a landscape perspective, but soil and landscape, the major components, are considered separately and assigned a value between 0 and 100 (Leskiw 1998).

The land capability classes are defined by Leskiw (1998) as follows:

> **Class 1 High Capability** (Index 81 to 100): Land having no significant limitations to supporting productive forestry, or only minor limitations that will be overcome with normal management practices.
>
> **Class 2 Moderate Capability** (Index 61 to 80): Land having limitations which in aggregate are moderately limiting for forest production. The limitations will reduce productivity or benefits, or increase inputs to the extent that the overall advantage to be gained from the use will still be attractive, but appreciably inferior to that expected on Class 1 land.
>
> **Class 3 Low Capability** (Index 41 to 60): Land having limitations which in aggregate are moderately severe for forest production. The limitations will reduce productivity or benefits, or increase inputs to the extent that the overall advantage to be gained from the use will be low.
>
> **Class 4 Conditionally Productive** (Index 21 to 40): Land having severe limitations; some of which may be surmountable through management, but which cannot be corrected with existing knowledge.
>
> **Class 5 Non-Productive** (Index 0 to 20): Land having limitations which appear so severe as to preclude any possibility of successful forest production.

4.2.2 Land capability subclasses

Land Capability Subclasses indicate the type of limitation including, under chemical parameters, nutrient retention capacity, acidity/alkalinity, salinity and sodicity/saturation percentage. The other soil categories are physical parameters (available water holding capacity, structure/consistence, organic carbon, and surface peat) and edaphic regime (soil moisture regime and soil nutrient regime). The landscape land capability subclasses include slope, exposure, stoniness and erosion (Leskiw 1998).

4.2.3 Interim and final ratings

Three principal layers are used to provide an interim rating: topsoil (TS, A or O horizon), upper subsoil (US, B or O horizon) and lower subsoil (LS, BC, C or O horizon) (Leskiw 1998). Following the interim rating, soil moisture and nutrient regimes are determined and adjustments to the interim rating may be made, resulting in a final soil rating. Landscape factors which affect tree growth are rated the same for undisturbed and reclaimed lands. The identification of the natural vegetation and its productivity is related to the site by the ecosite, ecoregion, etc. (Leskiw 1998). The productivity levels targeted for the reclaimed area should be equivalent to those on undisturbed lands, with the same quantity of inputs (Leskiw 1998).

4.2.4 Soil reaction (pH)

Soil pH has an influence on tree growth and productivity. Ideally, the soil should be slightly acidic for the nutrient supply to be balanced (Leskiw 1998). Deviating from slightly acid lowers forest productivity; soils with a pH < 5.0 and pH > 7.0 lower productivity (Table 5) (Leskiw 1998). However, Leskiw (1998) cautions that pH tolerance will vary with each plant species. In addition, high pH values are often associated with saline or sodic conditions, so if salinity or sodicity is present along with a high pH, there is only one penalty.

Table 5. Surface soil reaction deductions

Topsoil pH (H_2O)[1]	Topsoil pH ($CaCl_2$)[1]	Percent Deduction
≥ 9.0	≥ 8.5	80
8.5	8	40
8	7.5	20
7.5	7	10
5.0 to 7.0	4.5 to 6.5	0
4.5	4	10
4	3.5	20
3.5	3	40
≤ 3.0	≤ 2.5	80

[1] Round off to nearest 0.5 units, pH (H_2O) is the regulatory standard.
From Leskiw (1998).

4.2.5 Salinity

The presence of soluble salts such as sodium sulfates, magnesium sulfates and sodium chlorides in excessive amounts is referred to as salinity. Electrical conductivity is most commonly expressed as dS/m of salinity, although it can also be expressed in millimoles (mM) of a particular salt. An EC > 2 dS/m is a deduction to the topsoil rating by 10%, while an EC of 6 dS/m is a deduction to the topsoil rating by 50% and an EC of 11 dS/m leads to a deduction of 100% (Leskiw 1998). The deductions are based on the percentage growth decrease per dS/m increase in various tree species researched by McKenzie et al. (1994). Not all the species listed are native to the boreal forest, but Leskiw (1998) states that they were included for reference as it is the best information available. Boreal plant species researched by McKenzie et al. (1994) are included in this report in Part II, Section 9.0.

4.2.6 Sodicity and saturation percentage

Soil aggregate stability will decrease markedly when the SAR increases above 12 and the associated pH is usually greater than 8.5 (Leskiw 1998). Clays and organic matter disperse to form a massive and sticky soil when wet and an extremely hard, massive soil when dry (Leskiw 1998). This type of soil physical condition is difficult for growth of many plant species.

Saturation percentage (Sat%) is closely related to SAR in loamy soils or soils of finer texture (Leskiw 1998). When evaluating a soil, the most limiting of SAR or Sat% is used (Leskiw 1998). Non-sodic soils (SAR of 4 or less) may have a high Sat% if there is a high organic matter content, so no deductions should be taken. Coarse topsoils without clays will not receive deductions for SAR as the soil structure will not be affected by the SAR. However, trees may still be sensitive to sodium, depending on the species, so a high SAR may impede growth without affecting soil structure (Leskiw 1998).

A SAR of 4 (no equivalent Sat%) is a topsoil deduction of 10%; SAR 6 or a Sat% of 60 is a 15% and 10% reduction, respectively; SAR of 8 or Sat% 80 is a 20% deduction; SAR of 12 or Sat% 120 is a 45% deduction and a SAR of 16 or Sat% of 160 is a 70% deduction (Leskiw 1998). Therefore, only at SAR 4 and 6 (equivalent to Sat% 40 and 60) is the percent deduction for SAR and Sat% different.

5.0 SUMMARY

The majority of the research on boreal forest plant species and salinity has been conducted in the greenhouse or a short-term field study less than 2 years in duration. Greenhouse research, while valuable as a starting point, does not provide the long term exposure to the many environmental variables that can seriously impair plant growth such as weather, insects, competition and disease. Short-term research does not take into account the ability of a plant's tolerance limits to change with maturity.

Several researchers exposed young seedlings to saline soils following germination in a non-saline media which may have induced salt shock in some species. Therefore, a plant species' tolerance for salinity may be greater than results indicate, but based on the age of the seedling and instant exposure to large concentrations of saline ions, the plant may not be able to activate tolerance or avoidance mechanisms. Research with gradually increasing concentrations of salinity or long term research whereby the plant germinates and establishes in a non-saline media, but may be forced to root into saline subsoil, may be a more accurate representation of reclamation in the oil sands.

Field research in undisturbed boreal areas conducted by Burchill and Kenkel (1991), Lieffers (1984) and Yarie et al. (1993) provides the best insight into plant species tolerances for areas of high salinity and pH. There was no species overlap among these studies, so it is difficult to determine if a particular species would exhibit the same tolerances in another region. In addition, given the genetic variation within a species, it is too early to advocate changing the EC and pH values provided by Macyk et al. (1993) and Leskiw (1998) based on these research findings.

Some grass species appear to have a greater tolerance for salinity, but most of the research has been conducted in the prairie regions. The difference in ecoregion combined with the difference in soil texture and possibly type of salt may influence sustainable growth. Additional research in a boreal environment and/or in oil sands reclamation trials is required before values determined by Macyk et al. (1993) or Leskiw (1998) could be changed. A further consideration is that ecosystems in the boreal are composed of a variety of plant types. Grass species that are tolerant of boreal conditions are important, especially for erosion control and nutrient cycling. However, forb, shrub and tree species will also be required to reclaim a boreal ecosystem.

Based on the research reviewed in this report, changing the values for EC determined by Macyk et al. (1993) or Leskiw (1998) would be premature. Much of the research has been conducted in a greenhouse and was a short-term research initiative. Results from some studies suggest there may be saline tolerant species, but overall, the data are inconclusive. Further investigation of all plant species is required as most species have been tested in one or two experiments which have not been replicated. In addition to replication of the experiments, long term field studies, such as the research conducted by HBT AGRA (1994) needs to be conducted with higher EC and SAR values.

Revising the values of SAR and pH advocated by Macyk et al. (1993) and Leskiw (1998) is not advised for any species, given the absence of research in these areas. Research on SAR has not been conducted and pH research has not been conducted without the influence of salinity. The genetic variation to tolerate more alkaline pHs within some species may make revegetation growth sustainable, but only a small percentage of the original members may survive. The combination of higher concentrations of saline ions and more alkaline pH may be detrimental to many plant species in a drought or other stressful environmental conditions.

5.1 Future Research Needs

Based on the current available research data, limits for soil salinity, sodicity and pH should remain at the levels indicated by Macyk et al. (1993) and Leskiw (1998) for all plant species considered in Part II. Further long term field research is required for all species considered for boreal reclamation. Research objectives could focus on salt tolerance and genetic predisposition within a species for salt tolerance and a longer, possibly lifetime exposure. For oil sands reclamation, long term research is essential as salt concentrations may change with leaching, discharge of CT water and rooting into the saline overburden. Although salinity in the boreal forest is rare, undisturbed boreal sites that are saline should be researched thoroughly to identify soil chemical properties and associated plant species. Plant species adapted to saline conditions and native to the boreal forest will have greater potential to achieve equivalent capability and therefore sustainable growth during drought, insect infestations and other stressful environmental conditions. Therefore, further research is required to identify species native to the area that are adapted to saline conditions. Maximum tolerable soil salinity concentrations should be identified and used to determine criteria for reclamation.

Plant tolerance values for SAR and pH are worthy of further research. However, the influence of salinity may make it difficult to isolate SAR and pH tolerance ranges for many species. High SAR is usually associated with an alkaline pH so it may be difficult to determine which factor is most detrimental to plant germination, growth or survival.

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7.0 APPENDIX

Table 6. Values for salinity, sodicity and pH

Contaminant	EC (dS/m)	SAR	pH
Suncor CT Water[1]	0.98 to 1.68	NA	7.8 to 8.4
Syncrude CT Water[2]	<1 to 7.9	NA	5.26 to 8.41
Brine from Swan Hills Field[3]	60	NA	7.03
Brine from Oil Battery[4]	187	NA	NA
KCl Drilling Mud (3 sites)[5]	6.2 to 37.2	35.7 to 111.2	8.0 to 8.5
Dispersed Water/Gel Drilling Mud (3 sites)[5]	1.2 to 2.0	3.8 to 18.2	8.1 to 8.8
Flocculated Water/Gel Drilling Mud (4 sites)[5]	1.5 to 3.2	10.0 to 37.9	8.0 to 9.3
NaCl Drilling Mud (average 9 sites)[6]	39	NA	7.61
Rain Water[7]	NA	NA	5.6 to 5.9
<u>Soil and Overburden</u>			
Undisturbed Soils near Syncrude: 10 cm mineral horizon[8]	0.06 to 0.33	0.2 to 1.9	4.8 to 6.0
Undisturbed Soils near Syncrude: Surface organic layers[8]	0.32 to 1.03	0.2 to 1.9	NA
Mesic peat[8]	NA	NA	5.4 to 7.5
Fibric peat[8]	NA	NA	3.6 to 4.2
Clearwater Overburden[9]	4 to 11	NA	NA

NA: Not Available

[1]Nix (1983).

[2]Renault and Zwiazek (1997).

[3]Webster and Innes (1981).

[4]Canadian Association of Petroleum Producers (1996).

[5]Canadian Petroleum Association (1980).

[6]Macyk et al. 1992; Can-Ag Enterprises Ltd. (1986).

[7]Kaufman and Franz (1993).

[8]Undisturbed soils Macyk and Turchenek (1995) pH values obtained using water.

[9]Qualizza (personal communication).

Table 6. Values for salinity, sodicity and pH (con't)

Criteria/Guidelines	EC (dS/m)	SAR	pH
Alberta Tier I Criteria[10]	2	6	6.5 to 8.5
Soil Quality Criteria-Northern Forest Region, Good Rating[11]	< 2	< 4	5.0 to 6.5
CCME Agricultural Soil Criteria[12]	2	5	6 to 8
CCME Commercial Soil Criteria[12]	4	12	6 to 8
CCME Commercial Soil Criteria[12]	4	12	6 to 8
CCME Water Quality Guidelines for Protection of Aquatic Life-Freshwater[12]	NA	NA	6.5 to 9.0
CCME Water Quality Guidelines for Protection of Aquatic Life-Marine Water[12]	NA	NA	7.0 to 8.7

[10]Alberta Environment (1994).
[11]Macyk et al. (1993).
[12]Canadian Council of Ministers of the Environment (1999).

PART II

8.0 HOW TO USE THIS DOCUMENT

Based on the availability of information, each species has been given a tolerance range for EC, SAR and/or pH. A tolerance range does not imply a plant species' growth is sustainable within that range, only that research results from at least one particular study indicated plant survival, and possibly growth, occurred during the experiment, given specific conditions. Changing the research environment or other specifics of the experiment may change a plant species' tolerance for the stated salinity, sodicity or pH values.

If one study has been conducted, the value or range of values from that research is used as an indicator of tolerance if the plants survived. Where more than one study has been cited, the assignment of specific values to a tolerance range is dependent on the range of values. The research initiative that encompasses the largest range of values or most extreme value is used. Tolerances for EC, SAR and pH may be acquired from different studies for individual species. For example, if Study A provided values for EC only and Study B provided values for SAR and pH for the same species, values from each study would be used. For pH, if two studies indicate diverse tolerances, one acidic and one alkaline, both values would be used to show tolerance.

There are three possible confidence limits for each plant species: data are fairly conclusive, data are suggestive or data are inconclusive. Data considered fairly conclusive for a plant species would involve at least 3 studies: one with data collected from a saline undisturbed area and the remaining data from two long term field research initiatives. Plant health and EC, SAR and pH tolerances must be similar amongst the studies.

Woody plant species have a significantly longer life span than grasses and forbs which entails a greater risk for sustainability over several decades. For data to be considered suggestive for a woody plant species, one study from a undisturbed saline area is necessary and at least two field research initiatives which have similar results. Data for grasses and forbs are considered suggestive if at least two research initiatives have been conducted including one field study greater than 2 years in duration. Both studies should indicate similar results.

Data considered to be inconclusive for any plant species originate from: one undisturbed area only or; one or two short term greenhouse or field research initiatives or; a variety of research areas (undisturbed saline, long term field, greenhouse, etc.) which produced contradictory results.

If data from three or more studies are determined to be considered fairly conclusive for a plant species, the limits stated by Macyk et al. (1993) and Leskiw (1998) could be changed to reflect the different tolerance level. Suggestive data for a plant species indicate the current limits will be retained but additional research is necessary to determine if the tolerance levels may be altered in the future. Inconclusive data for a plant species indicate the values will be retained and several more studies that yield similar results are required for the limits to be changed. If the data are inconclusive due to research conducted at only one undisturbed site, short and long reclamation research should be considered to verify suitability for reclamation.

When a species died from exposure to a specific concentration of salinity, the tolerable level of salinity will be less than the concentration that caused mortality and the tolerable EC, SAR and pH values are considered unknown. If more than one study is available and the species survived, values for EC, SAR and pH from that research will be used.

Literature review information obtained from Hardy BBT (1989) and Edwards (1985) does not provide details on the type of research conducted to arrive at the tolerance values. The literature reviews are included in Part II to provide a comprehensive overview of the research, but determining if the data are fairly conclusive, suggestive or inconclusive based on these literature reviews is not possible.

Additional sources of generic information on plant tolerances are available in Manual of Plant Species Suitability for Reclamation in Alberta 2nd edition (Hardy BBT 1989), Revegetating with Native Grasses (Wark and Ducks Unlimited Canada 1995), Guideline for Wetland Establishment on Reclaimed Oil Sands Leases (Oil Sands Wetlands Working Group 2000) and A Guide to Using Native Plants on Disturbed Lands (Gerling et al. 1996). Please refer to Table 7 for a summary of the research conducted on plant species described in Part II and additional sources of information.

Table 7. Summary of research conducted on plant species described in Part II

Plant Species - Latin Name	Plant Species - Common Name	No. of Studies	Characteristics Studied	Type of Research	Other Publications
Grasses					
Agropyron dasystachyum	Northern wheatgrass	2	EC, pH	F, G	MPS, NP, RNG
Agropyron elongatum	Tall wheatgrass	1	EC	F	MPS, WE
Agropyron intermedium	Intermediate wheatgrass	1	EC	F	MPS, WE
Agropyron riparium	Streambank wheatgrass	2	EC, pH	F, G	MPS, RNG
Agropyron smithii	Western wheatgrass	2	EC	F, L	MPS, NP, RNG
Agropyron trachycaulum	Slender wheatgrass	3	EC, pH	F, G, VSI	MPS, NP, RNG, WE
Agropyron trichophorum	Pubescent wheatgrass	1	EC	F	MPS
Agrostis alba	Redtop	1	EC	F	MPS
Agrostis palustris	Creeping bentgrass	1	EC	F	
Bromus biebersteinii	Meadow brome	1	EC	F	
Calamagrostis canadensis	Bluejoint reedgrass	1	EC, pH	VSI	MPS, NP, WE
Calamagrostis inexpansa	Northern reedgrass	2	EC, pH	VSI	NP, WE
Dactylis glomerata	Orchardgrass	1	EC	F	MPS
Distichlis stricta	Saltgrass	2	EC, pH	VSI, L	MPS, NP, WE
Elymus angustus	Altai wildrye	1	EC	F	WE
Elymus dahuricus	Dahurian wildrye	1	EC	VSI	WE
Elymus junceus	Russian wildrye	1	EC	F	WE
Festuca arundinacea	Tall fescue	2	EC	F, L	MPS, WE
Festuca ovina	Sheep fescue	2	EC, pH	F, G	MPS, NP
Festuca rubra	Creeping red fescue	1	EC	F	MPS
Hierochloe odorata	Sweet grass	1	EC, pH	VSI	NP, WE
Hordeum jubatum	Foxtail barley	1	EC, pH	VSI	MPS, NP, WE
Phalaris arundinacea	Reed canary grass	2	EC	F, L	MPS, NP, WE
Phleum pratense	Timothy	2	EC	F, L	MPS
Poa alpina	Alpine bluegrass	1	EC, pH	G	MPS, NP
Poa pratensis	Kentucky bluegrass	2	EC, pH	F, G	MPS, NP, WE
Puccinellia distans	Weeping alkaligrass	1	EC	F	MPS
Puccinellia nuttalliana	Alkali grass	1	EC, pH	VSI	NP, WE
Spartina gracilis	Alkali cord grass	1	EC, pH	VSI	NP, WE
Forbs					
Antenaris pulcherrima	Showy everlasting	1	EC, pH	VSI	
Atriplex patula	Orache	1	EC, pH	VSI	
Epilobium angustifolium	Fireweed	1	EC, pH	VSI	MPS, NP, WE
Fragaria virginiana	Strawberry	1	EC, pH	G	WE
Geocaulon lividum	Bastard toad flax	1	EC, pH	VSI	
Glaux maritima	Sea milkwort	1	EC, pH	VSI	WE
Glycyrrhiza lepidota	Wild licorice	1	EC, pH	G	
Grindelia squarrosa	Gumweed	1	EC, pH	VSI	NP, WE
Helianthus annuus	Common annual sunflower	1	EC, pH	G	
Helianthus maximilianii	Sunflower	1	EC, pH	VSI	RNG
Linnaea borealis	Twinflower	2	EC, SAR, pH	F, VSI	
Moehringia lateriflora	Blunt-leaved sandwort	1	EC, pH	VSI	
Parnassia palustris	Northern grass of parnassus	1	EC, pH	VSI	
Plantago maritima	Sea-side plantain	1	EC, pH	VSI	WE
Pyrola asarifolia	Common pink wintergreen	1	EC, pH	VSI	
Pyrola secunda	One-sided wintergreen	1	EC, pH	VSI	
Salicornia rubra	Red samphire	1	EC, pH	VSI	NP, WE
Solidago canadensis	Canada goldenrod	1	EC, pH	VSI	RNG, WE
Spergularia marina	Sand spurry	1	EC, pH	VSI	WE
Suaeda depressa	Seablite	1	EC, pH	VSI	WE
Vicia americana	American vetch	1	EC, pH	G	MPS, RNG, WE

Table 7. Summary of research conducted on plant species described in Part II (con't)

Plant Species - Latin Name	Plant Species - Common Name	No. of Studies	Characteristics Studied	Type of Research	Other Publications
Shrubs					
Alnus crispa	Green alder	2	EC, SAR, pH	F, G	MPS, NP
Alnus rubra	Red alder	1	EC, pH	G	
Alnus tenuifolia	Thinleaf alder	1	EC, pH	VSI	MPS
Amelanchier alnifolia	Saskatoon	1	EC	F	NP, RNG
Arctostaphylos uva-ursi	Bearberry	1	EC, SAR	F	MPS, NP
Betula glandulosa	Swamp birch	2	EC, SAR, pH	F, L	
Betula occidentalis	Water birch	1	EC	G	
Cornus canadensis	Bunchberry	2	EC, SAR, pH	F, VSI	
Cornus stolonifera	Dogwood	7	EC, SAR, pH	F, G, L, VSI	MPS, NP, MPS
Ledum groenlandicum	Labrador tea	1	EC, SAR, pH	F	NP
Potentilla fruticosa	Shrubby cinquefoil	1	EC	F	NP
Prunus virginiana	Chokecherry	2	EC	G, L	MPS, NP, RNG
Rosa acicularis	Prickly rose	2	EC, pH	VSI	MPS, NP, WE
Rosa woodsii	Rose	2	EC, pH	F, G	MPS, NP
Rubus idaeus	Raspberry	2	EC, pH	F, G	MPS, NP
Salix alaxensis	Alaska willow	1	EC, pH	VSI	
Salix brachycarpa	Short-capsuled willow	1	EC, pH	VSI	
Salix nova-anglaea	Low blueberry willow	1	EC, pH	VSI	
Shepherdia canadensis	Buffaloberry	1	EC, pH	G	MPS, NP, RNG, WE
Symphoricarpos albus	Snowberry	1	EC, pH	VSI	WE
Vaccinium myrtilloides	Blueberry	1	EC, SAR, pH	F	
Virburnum edule	Low-bush cranberry	2	EC, SAR, pH	F, VSI	
Trees					
Abies balsamea	Balsam fir	2	EC, SAR, pH	F, L	
Betula papyrifera	Paper birch	2	EC	F, L	MPS, NP
Picea glauca	White spruce	11	EC, SAR, pH	F, G, VSI	MPS, NP, WE
Picea mariana	Black spruce	5	EC, SAR, pH	F, G, L	NP
Pinus banksiana	Jack pine	6	EC, SAR, pH	F, G, L	MPS, NP
Pinus contorta	Lodgepole pine	1	EC, pH	G	MPS, NP
Populus sp.	Northwest hybrid poplar	4	EC, SAR, pH	F, G	
Populus balsamifera	Balsam poplar	2	EC, pH	G, VSI	MPS, NP
Populus tremuloides	Trembling aspen	8	EC, SAR, pH	F, G, L, VSI	MPS, NP
Salix amygdaloides	Peachleaf willow	2	EC, SAR, pH	F, G	
Salix interior	Narrow-leaved willow	1	EC, pH	VSI	
Salix lasiandra	Pacific willow	1	EC, pH	VSI	
Riparian Grasses					
Scirpus maritimus	Prairie bulrush	1	EC, pH	VSI	WE
Scolochloa festucacea	Spangletop	1	EC, pH	VSI	RNG, WE
Triglochin maritima	Seaside arrowgrass	2	EC, pH	VSI	WE
Riparian Sedges					
Carex atherodes	Awned sedge	1	EC, pH	VSI	MPS, NP, WE

F-Field Research
G-Greenhouse Research
L-Literature Review
VSI-Vegetation and Soils Inventory, undisturbed area
MPS- Manual of Plant Species Suitability for Reclamation in Alberta (Hardy BBT Ltd. 1989)
NP-A Guide to Using Native Plants on Disturbed Lands (Gerling et al. 1996)
RNG-Revegetating with Native Grasses (Wark and Ducks Unlimited 1995)
WE-Guideline for Wetland Establishment on Reclaimed Oil Sands Leases (Oil Sands Wetlands Working Group 2000)

9.0 DRYLAND SPECIES

9.1 Grasses

Agropyron dasystachyum **Northern wheatgrass**

EC Tolerance Range: 2 to > 9 dS/m with sufficient soil moisture (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 6.0 to 9.5 for cultivar Elbee (USDA 1961)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Northern wheatgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	21	12
Moderate salinity zone	28	10
High salinity zone	22	8

Note: All values are approximate.
(McKenzie and Najda 1994)

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are included in Part II of this report.

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 6.0 to 9.5 for cultivar Elbee (USDA 1961)

Notes: Hardy BBT (1989) indicates northern wheatgrass has moderate tolerance to salinity, but specific values are not provided. The cultivar Elbee has been reported to tolerate a range of soil reaction (pH 6.0 to 9.5) and it tolerates considerable alkalinity (USDA 1961).

Agropyron elongatum **Tall wheatgrass**

EC Tolerance Range: 11 to 16 dS/m (White and de Jong 1975)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Tall wheatgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	35	12
Moderate salinity zone	40	18
High salinity zone	38	11

Note: All values are approximate.
(McKenzie and Najda 1994)

At Millicent, tall wheatgrass and dahurian wildrye were the highest yielding in all saline zones in 1991(McKenzie and Najda 1994). In 1992 and 1993, tall wheatgrass was the highest yielding in the most saline zone with Russian wildrye and smooth brome grass (McKenzie and Najda 1994). At Sheerness, tall wheatgrass yielded the most in the high and moderate salinity zones in 1992 (McKenzie and Najda 1994). In 1991 and 1993, the differences in yields between varieties were often not significant (McKenzie and Najda 1994).

Literature Review - Salinity Tolerance

EC: 11 to 16 dS/m (White and de Jong 1975)

SAR: not available

pH: not available

Notes: Hardy BBT (1989) indicates tall wheatgrass is reputed to be “the most salt tolerant of all cultivated grasses” (Best et al. 1971). General agreement that the species is highly adapted to saline soil conditions (Smoliak et al. 1975; Hanson 1972; USDA, Soil Conservation Service 1971; Kay 1978; Plummer et al. 1955; Hafenrichter et al. 1968; White and de Jong 1975) and alkaline conditions (Granite Seed 1989). Grown successfully where as much as 1% soluble salts occur (Plummer et al. 1955). Variously noted to tolerate values for EC from 11 to 16 dS/m (White and de Jong 1975) and between 8 to 15 dS/m (Laidlaw 1977). May even tolerate higher levels (USDA, Soil Conservation Service 1971; Ducks Unlimited (Canada) 1969). Tall wheatgrass is tolerant to very tolerant of alkaline soil conditions but specific pH values are not provided.

Agropyron intermedium **Intermediate wheatgrass**

EC Tolerance Range: 5 to 10 dS/m (White and De Jong 1975; Ducks Unlimited (Canada) 1969)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Intermediate wheatgrass (*Agropyron intermedium*) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	35	14
Moderate salinity zone	33	17
High salinity zone	22	7

Note: All values are approximate.
(McKenzie and Najda 1994)

Literature Review - Salinity Tolerance

EC: 5 to 10 dS/m (White and De Jong 1975; Ducks Unlimited (Canada) 1969)

SAR: not available

pH: not available

Notes: Hardy BBT (1989) indicates intermediate wheatgrass has a moderate tolerance to salinity and will withstand EC values of 5 to 10 dS/m (White and De Jong 1975; Ducks Unlimited (Canada) 1969). It prefers non-alkaline land (Hafenrichter et al. 1968) but tolerates alkalinity better than acidity (Plummer 1977).

Agropyron riparium **Streambank wheatgrass**

EC Tolerance Range: 2 to > 9 dS/m with sufficient soil moisture (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 8.2 (Naeth et al. 1999)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Streambank wheatgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	16	10
Moderate salinity zone	23	10
High salinity zone	17	7

Note: All values are approximate.
(McKenzie and Najda 1994)

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are included in Part II of this report.

Agropyron smithii Western wheatgrass

EC Tolerance Range: 9.1 to 21.2 dS/m (Smoliak and Johnston 1983)

SAR Tolerance Range: not available

pH Tolerance Range: > 5.0 (Jurgens 1972)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Western wheatgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	17	8
Moderate salinity zone	19	8
High salinity zone	15	5

Note: All values are approximate.
(McKenzie and Najda 1994)

Literature Review - Salinity Tolerance

EC: > 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for “low”, 1,500 to 3,000 ppm for “moderate” and > 3000 ppm for “high” (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report’s author.

Literature Review - Salinity Tolerance

EC: 9.1 to 21.2 dS/m (Smoliak and Johnston 1983)

SAR: not available

pH: > 5.0 (Jurgens 1972)

Notes: Hardy BBT (1989) indicates western wheatgrass has moderate (USDA, Soil Conservation Service 1976) to very high salt tolerance (Rowell and Crepin 1977). Cultivar Walsh performed well on a heavy clay mud-flat with electrical conductivities ranging from 9.1 to 21.2 dS/m (Smoliak and Johnston 1983). Emergence in the greenhouse of pregerminated seed and untreated seed was initially highest in 16 dS/m solution; however after 17 days emergence was greatest in solutions of 0 and 4 dS/m and much lower in solutions of 8 and 16 dS/m. The pregerminated seed had significantly better emergence after 17 days than the untreated seed (Mueller and Bowman 1989). Western wheatgrass seed had better emergence in the 16 dS/m solution than Russian wildrye and crested wheatgrass (Mueller and Bowman 1989).

Tolerance to alkaline soil conditions (Knipe 1973; USDA, Soil Conservation Service 1971; Best et al. 1971) is moderate. Satisfactory survival can be expected for acidic pH’s above 5.0 (Jurgens 1972).

Agropyron trachycaulum Slender wheatgrass

EC Tolerance Range: 9 to 21 dS/m (Smoliak and Johnston 1983)

SAR Tolerance Range: not available

pH Tolerance Range: 7.51 to 8.29 (Burchill and Kenkel 1991)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 11.1 dS/m; ± 1 standard deviation: 6.1 to 16.1 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.9, range 7.51 to 8.29 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Slender wheatgrass belongs to the Agropyron association.

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Slender wheatgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	33	15
Moderate salinity zone	36	14
High salinity zone	27	9

Note: All values are approximate.
(McKenzie and Najda 1994)

Slender wheatgrass was a high yielding grass in the first and second year but declined to less than average yield of the other grasses in the third year (McKenzie and Najda 1994).

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

Literature Review - Salinity Tolerance

EC: 9 to 21 dS/m (Smoliak and Johnston 1983)

SAR: not available

pH: 8.8 (Russell and Takyi 1979)

Notes: Hardy BBT (1989) indicates slender wheatgrass has a moderate to high tolerance to soil salinity (Canadian Land Reclamation Association 1977; USDA, Soil Conservation Service 1971; USDA, Soil Conservation Service 1979). Various tolerance ranges are quoted in the literature: 11 to 16 dS/m (468) and 8 to 15 dS/m (Laidlaw 1974). Established readily on a moderately saline clay with EC values ranging from 9 to 21 dS/m (Smoliak and Johnston 1983). Alberta oil sands at about 12 dS/m, though vigour was somewhat reduced (Takyi et al. 1977). In a greenhouse study herbage yield started to decline on soils with EC values greater than 10 dS/m, with 50% reduction at EC values about 16 dS/m. Slender wheatgrass was more tolerant than brome grass and reed canary grass but less tolerant than Russian wildrye, Altai wildrye grass and tall wheatgrass. Slender wheatgrass salinity tolerance varied with growth stage with germination being the most sensitive (McElgunn and Lawrence 1973). Some ecotypes are more salt tolerant than others.

Slender wheatgrass is considered moderately to highly tolerant of alkaline soil conditions (Smoliak et al. 1975; Hanson 1972). Successful on coarse textured overburden (pH 8.8) at Cadomin (Russell and Takyi 1979) though not successful on an alkaline tailings pond (pH 9.0) at an asbestos mine in Quebec where heavy metal may have also been a problem (Moore and Zimmerman 1977).

Agropyron trichophorum Pubescent wheatgrass

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Pubescent wheatgrass (*Agropyron trichophorum*) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	34	14
Moderate salinity zone	34	14
High salinity zone	26	9

Note: All values are approximate.
(McKenzie and Najda 1994)

Literature Review - Salinity Tolerance

EC: 4 to 8 dS/m (Laidlaw 1974)

SAR: not available

pH: not available

Notes: Hardy BBT (1989) indicates pubescent wheatgrass is fairly tolerant of soil salinity (Hanson 1972; USDA, Soil Conservation Service 1976), especially the Greenleaf cultivar. Rated as having moderate tolerance in the range of 4 to 8 dS/m (Laidlaw 1974). Seeding and planting recommendations in Montana, however, indicate that the species is poorly adapted to saline and alkaline sites (USDA, Soil Conservation Service 1971).

Pubescent wheatgrass prefers mildly acid, neutral or mildly alkaline conditions (Hafenrichter et al. 1968). Possibly favoring mildly alkaline conditions (Plummer 1977). Withstands more alkaline conditions than intermediate wheatgrass (USDA, Soil Conservation Service 1979).

Agrostis alba Redtop

EC Tolerance Range: 2 to > 9 dS/m **(**McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: > 4.5 (Rafaill and Vogel 1978)

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Redtop yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	36	na
Moderate salinity zone	32	na
High salinity zone	18	na

na: species not seeded at this location
Note: All values are approximate.
(McKenzie and Najda 1994)

Redtop and timothy were the 2 most salt sensitive forage species (McKenzie and Najda 1994). Redtop yielded 83%, 72% and 35% of the highest yielding species in the low, medium and high salinity zones, respectively (McKenzie and Najda 1994).

Literature Review - Salinity Tolerance

EC: 0 to 4 dS/m (Hardy BBT 1989)

SAR: not available

pH: > 4.5 (Rafaill and Vogel 1978)

Notes: Hardy BBT (1989) indicates that redtop has a low tolerance to saline soils (Laidlaw 1974; Rowell and Crepin 1977; Ducks Unlimited (Canada) 1969), notably soils that do not exceed 4 dS/m. Redtop is adapted to neutral, acid or very acid soils (Smoliak et al. 1975; Hanson 1972; Alaska Rural Development Council 1977; Hafenrichter et al. 1968; Bennet 1971). Good above pH 4.5 (Rafaill and Vogel 1978), though some records exist for occurrences below this level.

Agrostis palustris **Creeping bentgrass**

EC Tolerance Range: 2 to > 9 dS/m with adequate soil moisture (McKenzie and Najda (1994)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Creeping bentgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	8	1
Moderate salinity zone	9	2
High salinity zone	5	3

Note: All values are approximate.
(McKenzie and Najda 1994)

Creeping bentgrass, sheep fescue, hard fescue and Kentucky bluegrass had very poor salinity tolerance and usually significantly less growth than the other species in the high salinity zone at Millicent (McKenzie and Najda 1994).

Bromus biebersteinii Meadow brome

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Meadow bromegrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	38	13
Moderate salinity zone	34	12
High salinity zone	25	7

Note: All values are approximate.
(McKenzie and Najda 1994)

Meadow bromegrass was the highest yielding in the most saline zone at Millicent in 1993 along with tall wheatgrass, Russian wildrye and smooth bromegrass (McKenzie and Najda 1994).

Calamagrostis canadensis **Bluejoint reedgrass**

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 3.5 (Mitchell 1978); 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 3.5 (Mitchell 1978)

Notes: Hardy BBT (1989) indicates is moderately tolerant of saline soils. Bluejoint is tolerant of extremely acid soils, with pH values as low as 3.5 (Mitchell 1978).

Calamagrostis inexpansa Northern reed grass

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.6 to 8.2 (Burchill and Kenkel 1991)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 7.3 dS/m; ± 1 standard deviation: 3.8 to 10.9 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.9, range 7.6 to 8.2 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Northern reed grass is the dominant species in the Calamagrostis association.

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Dactylis glomerata **Orchardgrass**

EC Tolerance Range: 2 to > 9 dS/m with adequate soil moisture (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 4.5 (Skousen 1988)

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Orchardgrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	36	na
Moderate salinity zone	32	na
High salinity zone	21	na

na: species not seeded at this location
Note: All values are approximate.
(McKenzie and Najda 1994)

Literature Review - Salinity Tolerance

EC: 4 to 8 dS/m (Laidlaw 1974)

SAR: not available

pH: 4.5 (Skousen 1988)

Notes: Hardy BBT (1989) indicates orchard grass prefers calcareous soils (Hafenrichter et al. 1968); shows fair tolerance to salts (USDA, Soil Conservation Service 1976), in the range of 4 to 8 dS/m (Laidlaw 1974). It performs well on moderately acid, neutral or mildly alkaline soils (Hafenrichter et al. 1968). A lower limit of pH 4.5 has been suggested for the eastern US (Skousen 1988).

Distichlis stricta **Saltgrass**

EC Tolerance Range: 0 to 24 dS/m (White and de Jong 1975)

SAR Tolerance Range: not available

pH Tolerance Range: 7.4 to 8.2 (Burchill and Kenkel 1991)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 15.9 dS/m; ± 1 standard deviation: 10.3 to 21.6 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.8, range 7.4 to 8.2 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity are: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Foxtail barley and saltgrass are codominant in the Hordeum association (Burchill and Kenkel 1991).

Literature Review - Salinity Tolerance

EC: > 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Literature Review - Salinity Tolerance

EC: 0 to 24 dS/m (White and de Jong 1975)

SAR: not available

pH: not available

Notes: Hardy BBT (1989) indicates saltgrass is considered to have very high tolerance to saline conditions, possibly above 16 dS/m (Rowell and Crepin 1977; Whitman and Wali 1975). It is reported by others to withstand 2% salt and electrical conductivity in the range of 24 dS/m (White and de Jong 1975). Saltgrass well adapted to alkaline soil conditions (Best et al. 1971; Ludwig and McGinnies 1978; USDA, Soil Conservation Service 1979).

Elymus angustus **Altai wildrye**

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Altai wildrye (Prairieland variety) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	14	na
Moderate salinity zone	22	na
High salinity zone	20	na

na: species not seeded at this location.
Note: All values are approximate.
(McKenzie and Najda 1994)

The yield of Altai wildrye was not high because of a thin stand at Millicent (McKenzie and Najda 1994). It showed good salt tolerance and its yield in the high salinity zone was similar to the medium salinity zone (McKenzie and Najda 1994).

Altai wildrye (Ejay variety) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	0	8
Moderate salinity zone	0	7
High salinity zone	0	7

Note: All values are approximate.
(McKenzie and Najda 1994)

Elymus dahuricus **Dahurian wildrye**

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Dahurian wildrye yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	35	17
Moderate salinity zone	38	15
High salinity zone	33	10

Note: All values are approximate.
(McKenzie and Najda 1994)

Dahurian wildrye and tall wheatgrass were the highest yielding in all saline zones in 1991 at Millicent (McKenzie and Najda 1994). Dahurian wildrye and was high yielding in the first and second year but declined to less than average yield of the other grasses in the third year (McKenzie and Najda 1994). At Sheerness, Dahurian wildrye was the highest yielding grass in all salinity zones in 1992 (McKenzie and Najda 1994). In 1991 and 1993 the differences in yield were often not significant (McKenzie and Najda 1994).

Elymus junceus Russian wildrye

EC Tolerance Range: 11 to 16 dS/m (Ducks Unlimited (Canada) 1969; Plummer et al. 1955; Lawrence and Heinrichs 1966)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Russian wildrye yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	28	10
Moderate salinity zone	32	12
High salinity zone	30	8

Note: All values are approximate.
(McKenzie and Najda 1994)

Russian wildrye, tall wheatgrass and smooth bromegrass were the highest yielding in the most saline zone in 1992 and 1993 at Millicent (McKenzie and Najda 1994). At Millicent, Russian wildrye increased its relative yield in the high salinity zone from 7th highest in the first year to 2nd highest in the second year to highest in the third year (McKenzie and Najda 1994).

Literature Review - Salinity Tolerance

EC: 11 to 16 dS/m (Ducks Unlimited (Canada) 1969; Plummer et al. 1955; Lawrence and Heinrichs 1966)

SAR: not available

pH: not available

Notes: Hardy BBT (1989) indicates Russian wildrye has a high tolerance (11 to 16 dS/m) to salt (Ducks Unlimited (Canada) 1969; Plummer et al. 1955; Lawrence and Heinrichs 1966). A greenhouse trial of emergence in various saline solutions showed no statistically significant effects of salts up to 16 dS/m, although emergence was considerably lower in the 16 dS/m (691). The cultivar Sawki is noted for its salt tolerance (Elliott and Boton 1970). On alkaline sites it is more productive than crested wheatgrass (Plummer et al. 1955). Provided good growth on prairie coal mine waste with high salt content (Halland 1972).

Russian wild rye grows well on lime bearing soils, or at least those which are basic in reaction, rather than neutral or acid (Elliot and Boton 1970). Rated suitable for alkaline soils (Plummer 1977).

Festuca arundinacea **Tall fescue**

EC Tolerance Range: 8 to 12 dS/m (Laidlaw 1974; USDA, Soil Conservation Service 1971)

SAR Tolerance Range: not available

pH Tolerance Range: 4.5 to 8.0 (USDA, Soil Conservation Service 1973; Vogel and Berg 1968; Skousen 1988); pH 3.6 to 5.5 (Rafaill and Vogel 1978)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Tall fescue (Arid variety) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	36	5
Moderate salinity zone	34	8
High salinity zone	27	5

Note: All values are approximate.
(McKenzie and Najda 1994)

Arid yielded significantly more than the other species in the first year in all salinity zones at Millicent (McKenzie and Najda 1994). In the second and third years, tall fescue and creeping red fescue were the highest yielding species in the high salinity zone (McKenzie and Najda 1994). In the medium and low salinity zones in the second and third years, the tall, creeping red and sheep fescues were the highest yielding species (McKenzie and Najda 1994). Tall fescue also showed good yields at Sheerness in the high salinity zone (McKenzie and Najda 1994).

Tall fescue (Courtenay variety) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	38	na
Moderate salinity zone	37	na
High salinity zone	29	na

na: not seeded at this location.
Note: All values are approximate.
(McKenzie and Najda 1994)

Literature Review - Salinity Tolerance

EC: > 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Literature Review - Salinity Tolerance

EC: 8 to 12 dS/m (Laidlaw 1974; USDA, Soil Conservation Service 1971)

SAR: not available

pH: 4.5 to 8.0 (USDA, Soil Conservation Service 1973; Vogel and Berg 1968; Skousen 1988); pH 3.6 to 5.5 (Rafaill and Vogel 1978)

Notes: Hardy BBT (1989) indicates tall fescue has a fairly high tolerance of soil salinity. Upper tolerance limits of 8 to 12 dS/m have been reported (Laidlaw 1974; USDA, Soil Conservation Service 1971). It has been recommended as a useful pasture grass on wet or seep lands because of its tolerance to saline soils (Smoliak et al. 1975).

Tall fescue will grow on a wide range of soils from highly acidic to highly alkaline. Although the range of adaptation to pH has been given as 4.5 to 8.0 (USDA, Soil Conservation Service 1973; Vogel and Berg 1968; Skousen 1988), it probably has the widest soil reaction tolerance range of any commonly grown grass species (Elliot and Boton 1970). However, tall fescue has only satisfactory growth on mine spoil of pH 5.4 and has poor growth or failed completely on more acid spoils. Tall fescue has been recommended for planting on alkaline and calcareous spoil (pH 7.3) and acidic spoil (pH 3.6 to 5.5) in Kentucky (Rafaill and Vogel 1978).

Festuca ovina Sheep fescue

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 8.2 (Naeth et al. 1999)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Sheep fescue (*Festuca ovina*) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	27	11
Moderate salinity zone	24	9
High salinity zone	5	2

Note: All values are approximate.
(McKenzie and Najda 1994)

Hard fescue (*Festuca ovina* var. *duriuscula*) yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	26	na
Moderate salinity zone	28	na
High salinity zone	8	na

na: not seeded at this location.
Note: All values are approximate.
(McKenzie and Najda 1994)

In the medium and low salinity zones in the second and third years, the sheep, creeping red and tall fescues were the highest yielding species at Millicent (McKenzie and Najda 1994). Sheep fescue, Kentucky bluegrass, hard fescue and creeping bentgrass had very poor salinity tolerance and usually significantly less growth than the other species in the high salinity zone at Sheerness (McKenzie and Najda 1994). In 1993, at Sheerness, sheep fescue was the top yielding turfgrass in the low and medium salinity zones (McKenzie and Najda 1994).

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

Festuca rubra Creeping red fescue

EC Tolerance Range: 20 to 24 dS/m (Gardiner 1977)

SAR Tolerance Range: not available

pH Tolerance Range: 4.5 (Bennet et al. 1978)

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Creeping red fescue yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	31	na
Moderate salinity zone	32	na
High salinity zone	21	na

na: not seeded at this location.
Note: All values are approximate.
(McKenzie and Najda 1994)

In the second and third years, creeping red fescue and tall fescue were the highest yielding species in the high salinity zone at Millicent (McKenzie and Najda 1994). In the medium and low salinity zones in the second and third years, the creeping red, tall and sheep fescues were the highest yielding species (McKenzie and Najda 1994). Creeping red fescue showed limited growth at Sheerness in the high salinity zone (McKenzie and Najda 1994).

Literature Review - Salinity Tolerance

EC: 20 to 24 dS/m (Gardiner 1977)

SAR: not available

pH: 4.5 (Bennet et al. 1978)

Notes: Hardy BBT (1989) indicates creeping red fescue cultivar Arctared was successfully established on tailings with EC values of 20 to 24 dS/m. This was attributed to favorable early season precipitation (Gardiner 1977). Elsewhere, creeping red fescue was not affected by soil salinity of 5 dS/m, but plants appeared to lack vigor at soil salinity levels of 9 dS/m and 19 dS/m (Takyi et al. 1977). Creeping red fescue is tolerant of soil pH in the range of 4.5 (Bennet et al. 1978). It is also reported to grow on calcareous material (Smith and Bradshaw 1972).

Hierochloe odorata **Sweet grass**

EC Tolerance Range: 3.8 to 10.9 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.6 to 8.2 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 7.3 dS/m; ± 1 standard deviation: 3.8 to 10.9 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.9, range 7.6 to 8.2 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). Species in the Spartina, Agropyron, Calamagrostis and Rosa associations tolerate low salinity to no salinity (Burchill and Kenkel 1991). Sweet grass is found in the Calamagrostis association (Burchill and Kenkel 1991).

Hordeum jubatum Foxtail barley

EC Tolerance Range: 20 to 24 dS/m (Gardiner 1977)

SAR Tolerance Range: not available

pH Tolerance Range: 7.4 to 8.2 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 15.9 dS/m; ± 1 standard deviation: 10.3 to 21.6 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.8, range 7.4 to 8.2 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity are: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Foxtail barley and saltgrass are codominant in the Hordeum association (Burchill and Kenkel 1991).

Literature Review - Salinity Tolerance

EC: 20 to 24 dS/m (Gardiner 1977)

SAR: not available

pH: not available

Notes: Hardy BBT (1989) indicates foxtail barley is commonly found on soils that are slightly saline (Agricultural Potential Committee of the Alaska Rural Development Council 1974). It was successfully established on saline mine tailings with conductivities in the order of 20 to 24 dS/m (Gardiner 1977). Foxtail barley has been reported as a pioneer on saline mine spoils that are highly sodic in some areas (Murray 1977). It is an important component of the prairies cordgrass community characteristic of strongly saline soils. The EC in those locations range from 17 to 23 dS/m (Whitman and Wali

1975). It prefers basic soils and will not tolerate acidic soils (Kuja and Hutchinson 1979). Commonly found on somewhat alkaline sites (Agricultural Potential Committee of the Alaska Rural Development Council 1974).

Phalaris arundinacea **Reed canary grass**

EC Tolerance Range: 5 to 10 dS/m (White and de Jong 1975)

SAR Tolerance Range: not available

pH Tolerance Range: 5 (Down and Stocks 1977)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Reed canary grass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	33	na
Moderate salinity zone	30	na
High salinity zone	19	na

na: not seeded at this location.
Note: All values are approximate.
(McKenzie and Najda 1994)

Literature Review - Salinity Tolerance

EC: 2 to 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Literature Review - Salinity Tolerance

EC: 5 to 10 dS/m (White and de Jong 1975)

SAR: not available

pH: 5 (Down and Stocks 1977)

Notes: Hardy BBT (1989) indicates reed canary grass is moderately saline tolerant (USDA, Soil Conservation Service 1979). It can grow in soils with an EC of 5 to 10 dS/m (White and de Jong 1975). It should not be grown on strongly saline soils (Goplen et al. 1963).

Reed canary grass cultivar Frontier has very good acid tolerance (5). It has been recommended as part of a seed mix for vegetation of spoils with pH of at least 5.0 in Pennsylvania (Down and Stocks 1977). Also considered moderately alkaline tolerant (USDA, Soil Conservation Service 1979).

Phleum pratense Timothy

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 5.6 to 7.3 (USDA, Soil Conservation Service 1973); 4.5 (Rafaill and Vogel 1978; Down and Stocks 1977)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Timothy yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	36	na
Moderate salinity zone	32	na
High salinity zone	16	na

na: not seeded at this location.
Note: All values are approximate.
(McKenzie and Najda 1994)

Timothy and redtop were the 2 most salt sensitive forage species at Millicent (McKenzie and Najda 1994). Timothy yielded respectively 89%, 73% and 42% of the highest yielding species in the low, medium and high salinity zones (McKenzie and Najda 1994).

Literature Review - Salinity Tolerance

EC: < 2 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author. Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Literature Review - Salinity Tolerance

EC: 0 to 4 dS/m (Laidlaw 1974)

SAR: not available

pH: 5.6 to 7.3 (USDA, Soil Conservation Service 1973); 4.5 (Rafaill and Vogel 1978; Down and Stocks 1977)

Notes: Hardy BBT (1989) indicates timothy has a low tolerance to salt, in the range of 0 to 4 dS/m (Laidlaw 1974). It is regarded as acid tolerant (Vaartnou 1979). It has been identified as a successful species on acid (pH 3.5 to 5.3) mine wastes (overburden) treated with lime (Hubbard and Bell 1977). It has been recommended for growth on mine spoil with a pH range of 5.6 to 7.3 (USDA, Soil Conservation Service 1973). The lower pH limit for growth has been estimated at 4.5 (Rafaill and Vogel 1978; Down and Stocks 1977).

Poa alpina Alpine bluegrass

EC Tolerance Range: 4.075 dS/m (Naeth et al. 1999)

SAR Tolerance Range: not available

pH Tolerance Range: 8.2 (Naeth et al. 1999)

Confidence Limit: data are inconclusive

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

Poa pratensis Kentucky bluegrass

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda 1994)

SAR Tolerance Range: not available

pH Tolerance Range: > 5.5 (Skousen 1988); 8.2 (Naeth et al. 1999)

Confidence Limit: data are suggestive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Kentucky bluegrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	18	8
Moderate salinity zone	17	9
High salinity zone	4	4

Note: All values are approximate.
(McKenzie and Najda 1994)

Kentucky bluegrass, sheep fescue, hard fescue and creeping bentgrass had very poor salinity tolerance and usually significantly less growth than the other species in the high salinity zone at Millicent (McKenzie and Najda 1994).

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: > 5.5 (Skousen 1988)

Notes: Hardy BBT (1989) indicates Kentucky bluegrass has poor tolerance to soil salinity (USDA, Soil Conservation Service 1976). It has been noted as having only fair tolerance to soil acidity (Alaska Rural Development Council 1977); soil pH must be at least 5.5 for good growth (Skousen 1988). Kentucky bluegrass does well on soils of limestone origin (Bennet et al. 1978).

Puccinellia distans **Weeping alkaligrass**

EC Tolerance Range: 2 to > 9 dS/m (McKenzie and Najda)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: 2 to 15 dS/m at Millicent (Brooks, Alberta); 2 to 18 dS/m at Sheerness (Hanna, Alberta) (type of salt not available) (McKenzie and Najda 1994).

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	< 3 dS/m	< 4 dS/m
Moderate salinity zone	3 to 9 dS/m	4 to 9 dS/m
High salinity zone	> 9 dS/m	> 9 dS/m

SAR: not available

pH: not available

Notes: Research was conducted to determine the salinity tolerances of grass species at a dryland (Sheerness) and irrigated site (Millicent) over three years (McKenzie and Najda 1994). Twenty-five species of grass were seeded in 1990 and harvested each year to determine the productivity or yield of each species (McKenzie and Najda 1994). An EM38 salinity meter was used to determine the soil conductivity which was measured at the time of seeding and after each harvest (McKenzie and Najda 1994). Soil samples were also collected to correlate the EM38 readings to a saturated paste extract equivalent (McKenzie and Najda 1994). The combination of higher salinity and lower soil moisture at Sheerness may have contributed to the lower yields in the high saline zone for species normally considered salt tolerant (McKenzie and Najda 1994). Total dry matter yield for each species is over the three years of research from 1991 to 1993.

Weeping alkaligrass yields in t/ha:

	Millicent (irrigated)	Sheerness (dryland)
Low salinity zone	13	5
Moderate salinity zone	17	8
High salinity zone	10	8

Note: All values are approximate.
(McKenzie and Najda 1994)

Weeping alkali grass was the most salt tolerant of the turf grasses and yielded the most in the high salinity zone at Sheerness (McKenzie and Najda 1994). It appears to be better adapted to the dryland site (McKenzie and Najda 1994). Weeping alkali grass has salinity tolerance and its dry matter yield was more in the high salinity zone than the other zones likely because this zone had more moisture than the other zones (McKenzie and Najda 1994). In 1993, at Sheerness, it usually had lower dry matter yield than the other species in the low salinity zone (McKenzie and Najda 1994).

Puccinellia nuttalliana Alkali grass

EC Tolerance Range: 18.0 to 33.3 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 8.6 to 9.0 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 25.6 dS/m; ± 1 standard deviation: 18.0 to 33.3 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.8, range 8.6 to 9.0 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity are: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Seaside arrow-grass and alkali grass have the highest mean cover in the Salt Pan association (Burchill and Kenkel 1991).

Spartina gracilis Alkali cord grass

EC Tolerance Range: : 6.6 to 18.1 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.7 to 8.5 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 12.3 dS/m; ± 1 standard deviation: 6.6 to 18.1 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.1, range 7.7 to 8.5 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Alkali cord grass is the dominant species in the Spartina association (Burchill and Kenkel 1991).

9.2 Forbs

Antenaria pulcherrima Showy everlasting

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Atriplex patula Orache

EC Tolerance Range: 13.6 to 32.7 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.6 to 8.6 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 23.1 dS/m; ± 1 standard deviation: 13.6 to 32.7 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.1, range 7.6 to 8.6 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Orache is found with sea milkwort and sea-side plantain in the Triglochin association (Burchill and Kenkel 1991).

Epilobium angustifolium Fireweed

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Fragaria virginiana Strawberry

EC Tolerance Range: 1.03 to 6.55 dS/m (Renault et al. 1998a)

SAR Tolerance Range: not available

pH Tolerance Range: 5.12 to 7.42 (Renault et al. 1998a)

Confidence Limit: data are inconclusive

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A, 6.97 Treatment B, 7.4 Treatment C, 7.39 Treatment D, 7.42 Treatment E and 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a). Twenty-four 2 month old seedlings of strawberry were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all strawberry seedlings were alive in the control and Treatment B, 92% were alive in Treatment C, 71% were alive in Treatment D, 50% were alive in Treatment E and 29% were alive in Treatment F (Renault et al. 1998a). Leaf necrosis was observed in Treatment D (Renault et al. 1998a). Water potentials declined rapidly in Treatments C, D, E and F (Renault et al. 1998a). Transpiration rates were reduced compared to the control in Treatments E and F (Renault et al. 1998a). Membrane leakage was induced in the leaves of strawberry in all CT treatments (Renault et al. 1998a).

Geocaulon lividum Bastard toad flax

EC Tolerance Range: 14.39 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Glaux maritima Sea milkwort

EC Tolerance Range: 13.6 to 40.8 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.6 to 9.0 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: Salt Pan mean: 31.4 dS/m; Triglochin mean: 23.1 dS/m; ± 1 standard deviation: 13.6 to 40.8 dS/m (both groups combined) (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: range 7.6 to 9.0 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity are: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Sea milkwort is prominent in two associations: the Salt Pan and Triglochin (Burchill and Kenkel 1991).

Glycyrrhiza lepidota Wild licorice

EC Tolerance Range: 4.075 dS/m (Naeth et al. 1999)

SAR Tolerance Range: not available

pH Tolerance Range: 8.2 (Naeth et al. 1999)

Confidence Limit: data are inconclusive

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999).

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. The experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

Grindelia squarrosa **Gumweed**

EC Tolerance Range: 10.3 to 21.6 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.4 to 8.2 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 15.9 dS/m; ± 1 standard deviation: 10.3 to 21.6 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.8, range 7.4 to 8.2 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Gumweed is found with foxtail barley and saltgrass in the Hordeum association (Burchill and Kenkel 1991).

Helianthus annuus Common annual sunflower

EC Tolerance Range: 4.075 dS/m (Naeth et al. 1999)

SAR Tolerance Range: not available

pH Tolerance Range: 8.2 (Naeth et al. 1999)

Confidence Limit: data are inconclusive

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

Helianthus maximilianii **Sunflower**

EC Tolerance Range: : 1.3 to 10.9 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 7.8 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 6.1 dS/m; ± 1 standard deviation: 1.3 to 10.9 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.5, range 7.2 to 7.8 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Sunflower is an introduced species which had high cover in the Rosa association along with Canada goldenrod and perennial sow thistle (Burchill and Kenkel 1991).

Linnaea borealis **Twinflower**

EC Tolerance Range: 0.05 to 0.3 dS/m, undisturbed soil (Webster and Innes 1981); 8.75 to 14.92 dS/m undisturbed saline area (Yarie et al. 1993)

SAR Tolerance Range: < 0.20, undisturbed soil (Webster and Innes 1981)

pH Tolerance Range: 3.5 to 5.1, undisturbed soil (Webster and Innes 1981); 7.2 to 8.7 undisturbed saline area (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Site

EC: soil-solution: 8.75 to 14.92 dS/m at 50 cm; 7.15 to 14.59 dS/m at 150 cm; groundwater: 7.84 to 10.11 dS/m Stage VIII sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.7 to 8.7 at 50 cm; 7.4 to 7.8 at 150 cm; groundwater pH 7.2 to 8.0 Stage VIII sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage VIII (Yarie et al. 1993).

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981). Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

In July 1978, approx. 80% of the total cover for twinflower died following the brine treatment with no leaching, gypsum or fertilizer enhancements. In August 1979, there was 0% percent of the total cover, but the initial mortality was very high, so cover values were very low (approx. 1%) in 1979 (Hettinger 1981).

Moehringia lateriflora Blunt-leaved sandwort

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Parnassia palustris Northern grass of parnassus

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Plantago maritima Sea-side plantain

EC Tolerance Range: : 13.6 to 32.7 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.6 to 8.6 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 23.1 dS/m; ± 1 standard deviation: 13.6 to 32.7 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.1, range 7.6 to 8.6 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba in the boreal forest (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Sea-side plantain is found with sea milkwort and saltbush in the Triglochin association (Burchill and Kenkel 1991). It is a short-lived perennial (Burchill and Kenkel 1991).

Pyrola asarifolia **Common pink wintergreen**

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Pyrola secunda One-sided wintergreen

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Salicornia rubra **Red samphire**

EC Tolerance Range: 22.0 to 40.8 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 8.6 to 9.0 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 31.4 dS/m; ± 1 standard deviation: 22.0 to 40.8 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.8, range 8.6 to 9.0 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). The small salt-tolerant annuals, red samphire and sand spurry, have the highest frequency in the Salt Pan association (Burchill and Kenkel 1991).

Solidago canadensis **Canada goldenrod**

EC Tolerance Range: 1.3 to 10.9 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 7.8 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 6.1 dS/m; ± 1 standard deviation: 1.3 to 10.9 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.5, range 7.2 to 7.8 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Canada goldenrod had high cover in the Rosa association along with the introduced species, sunflower and perennial sow thistle (Burchill and Kenkel 1991).

Spergularia marina Sand spurry

EC Tolerance Range: 22.0 to 40.8 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 8.6 to 9.0 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 31.4 dS/m; ± 1 standard deviation: 22.0 to 40.8 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.8, range 8.6 to 9.0 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). The small salt-tolerant annuals, red samphire and sand spurry, have the highest frequency in the Salt Pan association (Burchill and Kenkel 1991).

Suaeda depressa Seablite

EC Tolerance Range: 22.0 to 40.8 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 8.6 to 9.0 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 31.4 dS/m; ± 1 standard deviation: 22.0 to 40.8 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 8.8, range 8.6 to 9.0 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Seablite is in the Salt Pan association (Burchill and Kenkel 1991).

Vicia americana American vetch

EC Tolerance Range: 4.075 dS/m (Naeth et al. 1999)

SAR Tolerance Range: not available

pH Tolerance Range: 8.2 (Naeth et al. 1999)

Confidence Limit: data are inconclusive

Greenhouse Research - Consolidated Tailings

EC: 4.075 dS/m (type of salt not provided) (Naeth et al. 1999)

SAR: not available

pH: 8.2 (Naeth et al. 1999)

Notes: This greenhouse research was conducted using consolidated tailings (CT) and recycled water from CT to maintain a 2 to 5 mm film of water on top of CT in growth cells (Naeth et al. 1999). Recycled water EC was 4.075 dS/m with a pH of 8.2 (Naeth et al. 1999). Trays were covered to minimize evaporation and maintain EC and pH values throughout the 6 week and 10 week trials. Experiment was conducted to measure germination and survival of grass and forbs species suitable for reclamation in the oil sands (Naeth et al. 1999). Species that exhibited the most success are highlighted in Part II of this report.

9.3 Shrubs

Alnus crispa **Green alder**

EC Tolerance Range: 0.3 to 3.2 dS/m (Alberta Environment 1982)

SAR Tolerance Range: 0 to 1.86 (Alberta Environment 1982)

pH Tolerance Range: 4.3 to 6.8 (Alberta Environment 1982); 8.0 (Crocker and Major 1955)

Confidence Limit: data are inconclusive

Field Research - Undisturbed Site

EC: 0.3 dS/m Ae, 0 to 12 cm; EC 2.8 dS/m, Bnt1 12 to 37 cm; EC 3.2 dS/m, Bnt2, 37 to 60 cm (Alberta Environment 1982).

SAR: 1.86 Ae, 0 to 12 cm; SAR 1.69, Bnt1, 12 to 37 cm; SAR 1.77, Bnt2, 37 to 60 cm (Alberta Environment 1982).

pH: 4.3, Ae, 0 to 12 cm; pH 6.0, Bnt1, 12 to 37 cm; pH 6.8, Bnt2, 37 to 60 cm (Alberta Environment 1982).

Notes: Soil survey of an undisturbed area west of Fort McMurray, Alberta, NW17-97-12-W4. Soil is a Gray Solodized Solonetz (Joslyn series). Larry Turchenek (personal communication), conducted the soil survey and recalled the vegetation in this area was short and stunted. Area was imperfectly drained, so the hydrology of the area may have also influenced vegetation health (Turchenek personal communication). Alder was associated with aspen and bunchberry (Alberta Environment 1982).

Greenhouse Hydroponics Research - Suncor CT Water (Study 97:8)

EC: 1.047 dS/m in control (Treatment A) (deionized water only); 1.455 dS/m with 25% CT water (Treatment B); 1.958 dS/m with 50% CT water (Treatment C); 2.958 dS/m with 100% CT water (Treatment D) and 4.44 dS/m with 100% CT water and 1420 ppm $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997).

SAR: not available

pH: not available

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997). Twenty-four seedlings of green alder were grown in a hydroponics system (Renault and Zwiazek 1997). None of the alder survived the 100% CT treatments, 17% survived the 25% CT treatment and 100% survived the 25% CT and control treatments (Renault and Zwiazek 1997). After 4 week treatments in 25% and higher CT water concentrations, alder seedlings showed leaf necrosis (Renault and Zwiazek 1997). Root growth was reduced in response to CT water (Renault and Zwiazek 1997). Water potentials were decreased in the 50% CT water treatment suggesting the seedlings were under stress (Renault and Zwiazek 1997). Salts were likely absorbed by some plants and the increasing concentration of ions could be directly responsible for a decrease in plant water potentials (Renault and Zwiazek 1997). Transpiration rates were significantly reduced in alder by all concentrations of CT water (Renault and Zwiazek 1997).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 8.0 (Crocker and Major 1955)

Notes: Hardy BBT (1989) indicates green alder's salinity tolerance is unknown, but presumed to be minimal. Green alder has a high acid tolerance (Alaska Rural Development Council 1977). The growth of alder planted on a sandy soil (pH 5.5) was reduced by the addition of lime (Fessenden and Sutherland 1979). However, green alder is often a pioneer on alkaline glacial outwash (pH 8.0) (Crocker and Major 1955). The closely related *A. viridis* is a continental alpine species that occurs naturally on soils from acid rocks and has been described as an acidophile. However, good growth has been reported for *A. viridis* in soil where their roots overlie chalk (Taylor and MacBryde 1977).

Alnus rubra **Red alder**

EC Tolerance Range: 1.02 to < 3.13 dS/m (Khasa and Hambling, personal communication)

SAR Tolerance Range: not available

pH Tolerance Range: 6.93 to 6.96 (Khasa and Hambling, personal communication)

Confidence Limit: data are inconclusive

Greenhouse Hydroponics Research - Saline Water

EC: 1.016 dS/m in control; 25mM NaCl, 3.13 dS/m (Treatment A); 50 mM NaCl, 6.33 dS/m (Treatment B); 75 mM NaCl, 8.80 dS/m (Treatment C) and; CT water from Syncrude, 4.10 dS/m (Treatment D) (Khasa and Hambling, personal communication).

SAR: not available

pH: 6.96 Control; 6.93 Treatment A; 6.94 Treatment B; 6.94 Treatment C; 8.06 Treatment D (Khasa and Hambling, personal communication).

Notes: Woody species were grown hydroponically in the greenhouse to determine their salt tolerance (Khasa and Hambling, personal communication). All treatments were made with 0.5% Hoagland's solution and the addition of salt or water (Khasa and Hambling, personal communication). There were 60 red alder seedlings in each treatment (Khasa and Hambling, personal communication). Exposure to the treatment commenced when the seedlings were 1 to 2 months old and lasted 1 month (Khasa and Hambling, personal communication). The seedlings were observed for chlorosis and survival after 1 month of exposure.

In the control, all red alder seedlings did not exhibit any chlorosis (Khasa and Hambling, personal communication). In Treatment A, at 3.13 dS/m, all seedlings had chlorosis: 31 red alder died, 3 had severe chlorosis, 6 had moderate chlorosis and 20 had light chlorosis (Khasa and Hambling, personal communication). In Treatments B (6.33 dS/m) and C (8.80 dS/m), all seedlings died (Khasa and Hambling, personal communication). In the CT water treatment (4.10 dS/m), 18 seedlings died, 15 had severe chlorosis, 16 had moderate chlorosis, 10 had light chlorosis and 1 had no chlorosis (Khasa and Hambling, personal communication).

Alnus tenuifolia **Thinleaf alder**

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Amelanchier alnifolia Saskatoon

EC Tolerance Range: 2.4 to 9.9 dS/m (McKenzie et al. 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 5.5 to 7.5 (Davidson n.d.)

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: Mean of 2.4 to 9.9 dS/m (type of salt not available) (McKenzie et al. 1994).

SAR: not available

pH: not available

Notes: To determine the salinity tolerance of 28 trees and shrubs, research was conducted near Brooks, Alberta for 5 years (McKenzie et al. 1994). The research included four species normally found in the boreal forest: shrubby cinquefoil, white spruce, saskatoon and paper birch. Six plants of each species were transplanted in spring 1989 into soil with varying degrees of salinity determined by using an EM38 salinity meter (McKenzie et al. 1994). Of the 5 zones of salinity, the highest zone had a mean salinity of 9.9 dS/m (McKenzie et al. 1994). Growth of each plant was measured at the beginning and end of each growing season for height, diameter at the widest point in the canopy and diameter at the narrowest point, usually the base (McKenzie et al. 1994). Dead plants were replaced until the end of 1991 (McKenzie et al. 1994). Saskatoon had a high average yearly mortality rate of 50% in the medium to high salinity zones (mean 6.4 to 9.9 dS/m) (McKenzie et al. 1994). The growth of saskatoon decreased 9.6% per dS/m increase (McKenzie et al. 1994).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 5.5 to 7.5 (Davidson n.d.)

Notes: Hardy BBT (1989) indicates saskatoon has no known tolerances for salinity and is not found in saline conditions (Davidson 1987). It is found on moderately acidic to moderately alkaline soils (338). Adapted to a wide range of soil reaction (Miller and Stushnoff 1970). Best growth on soils with a pH range 6.0 to 7.0 (Grainger personal communication) and can tolerate pH 5.5 to 7.5 (Davidson n.d.).

Arctostaphylos uva-ursi **Bearberry**

EC Tolerance Range: < 0.73 dS/m (Renault and Zwiazek 1997)

SAR Tolerance Range: < 1.2 (Renault and Zwiazek 1997)

pH Tolerance Range: unknown (Renault and Zwiazek 1997)

Confidence Limit: data are inconclusive

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;
- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;
- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away. Sixty bearberry seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997). Bearberry survival rates were low and physiological parameters were not measured. The bearberry seedlings wilted rapidly and lost foliage and very few plants recovered and resumed growth in any of the treatments (Renault and Zwiazek 1997).

Betula glandulosa Swamp birch

EC Tolerance Range: < 5.85 dS/m on spill site; < 1.00 dS/m on control site (Edwards and Blauel 1975)

SAR Tolerance Range: < 12.75 on spill site; 2.36 to 4.77 on control site (Edwards and Blauel 1975)

pH Tolerance Range: < 7.3 on spill site; on control site 4.3 to 4.9 (Edwards and Blauel 1975)

Confidence Limit: data are inconclusive

Field Research - Brine Spill

EC: Spill site: 5.85 dS/m at LFH (7.5 to 0 cm); 5.09 dS/m at Aej (0 to 5 cm); 4.07 dS/m at AB (5 to 30 cm); 1.79 dS/m at Bt1 (30 to 60 cm) with Ca, Na and Cl increasing most significantly compared to control (Edwards and Blauel 1975). Control site: EC < 1.00 dS/m throughout profile (Edwards and Blauel 1975).

SAR: Spill site: 12.75 at LFH (7.5 to 0 cm); 11.89 at Aej (0 to 5 cm); 8.45 at AB (5 to 30 cm); 3.12 at Bt1 (30 to 60 cm); 7.92 at Bt2 (60 to 75 cm). Control site: 2.36 at LFH (7.5 to 0 cm); 3.64 at Aej (0 to 5 cm); 3.02 at AB (5 to 30 cm); 3.95 at Bt1 (30 to 60 cm); 4.77 at Bt2 (60 to 75 cm). (Edwards and Blauel 1975).

pH: Spill site: 6.3 at LFH (7.5 to 0 cm); 5.8 at Aej (0 to 5 cm); 6.4 at AB (5 to 30 cm); 7.0 at Bt1 (30 to 60 cm); 7.3 at Bt2 (60 to 75 cm). Control site: 4.3 at LFH (7.5 to 0 cm); 4.4 at Aej (0 to 5 cm); 4.6 at AB (5 to 30 cm); 4.5 at Bt1 (30 to 60 cm); 4.9 at Bt2 (60 to 75 cm). (Edwards and Blauel 1975).

Notes: Swan Hills Site 19 was examined and sampled for changes in the Orthic Gray Luvisolic soil and vegetation following a brine spill in June 1973 (Edwards and Blauel 1975). Samples of the actual spill water were not obtained, but brine samples from storage tanks contained mainly sodium (22,400 mg/l) and chloride (34,600 mg/l) approximately double the concentration found in sea water (Edwards and Blauel 1975). There were 4 subplots at Site 19 with varying concentrations of Cl at 30 cm measured in August 1973: at 5,502 ppm Cl trees died (all foliage, bud and cambial tissues necrotic); at 62,568 ppm Cl trees dead; at 9,940 ppm Cl many trees dead by June, few survivors severely stressed; by September 1974; at maximum concentration of 520 ppm Cl in September 1974, there was leaf curl and discoloration of leaf tips was common, by September 1975 (290 ppm) the birch had a normal appearance (Edwards and Blauel 1975).

Literature Review - Salinity Tolerance

EC: 2 to 4 dS/m for birch species (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Betula occidentalis **Water birch**

EC Tolerance Range: 2.958 dS/m (Renault and Zwiazek 1997)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Greenhouse Hydroponics Research - Suncor CT Water (Study 97:8)

EC: 1.047 dS/m in control (Treatment A) (deionized water only); 1.455 dS/m with 25% CT water (Treatment B); 1.958 dS/m with 50% CT water (Treatment C); 2.958 dS/m with 100% CT water (Treatment D) and 4.44 dS/m with 100% CT water and 1420 ppm $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997).

SAR: not available

pH: not available

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997). Twenty-four seedlings of water birch were grown in a hydroponics system (Renault and Zwiazek 1997). After 4 weeks, survival of water birch was 100% in the control, 25% CT water and 50% CT water treatments (Renault and Zwiazek 1997). Survival was 83% in the 100% CT water and 50% in the 100% CT water plus $NaSO_4$ treatment (Renault and Zwiazek 1997). Leaf necrosis was observed only in the 100% CT water with $NaSO_4$ treatment (Renault and Zwiazek 1997). Water potentials were decreased only in the 100% CT water with $NaSO_4$ treatment (Renault and Zwiazek 1997). After 1 week, transpiration rates of birch seedlings were reduced in the 50% CT and higher concentration treatments, but after 4 weeks only the 100% CT water plus $NaSO_4$ treatment had a significant effect on transpiration rates (Renault and Zwiazek 1997).

Cornus canadensis **Bunchberry**

EC Tolerance Range: 0.3 to 3.2 dS/m (Alberta Environment 1982)

SAR Tolerance Range: 1.69 to 1.86 (Alberta Environment 1982)

pH Tolerance Range: 4.3 to 6.8 (Alberta Environment 1982)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Site

EC: 0.3 dS/m Ae, 0 to 12 cm; EC 2.8 dS/m, Bnt1 12 to 37 cm; EC 3.2 dS/m, Bnt2, 37 to 60 cm (Alberta Environment 1982).

SAR: 1.86 Ae, 0 to 12 cm; SAR 1.69, Bnt1, 12 to 37 cm; SAR 1.77, Bnt2, 37 to 60 cm (Alberta Environment 1982).

pH: 4.3, Ae, 0 to 12 cm; pH 6.0, Bnt1, 12 to 37 cm; pH 6.8, Bnt2, 37 to 60 cm (Alberta Environment 1982).

Notes: Soil survey of an undisturbed area west of Fort McMurray, Alberta, NW17-97-12-W4. Soil is a Gray Solodized Solonetz (Joslyn series). Larry Turchenek (personal communication), conducted the soil survey and recalled the vegetation in this area was short and stunted. Area was imperfectly drained, so the hydrology of the area may have also influenced vegetation health (Turchenek personal communication). Alder was associated with aspen and bunchberry (Alberta Environment 1982).

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981) Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

In July 1978, approx. 100% of the total cover was severely damaged for bunchberry following the brine treatment with no leaching, gypsum or fertilizer enhancements. In August 1979, the species was not observed (Hettinger 1981).

Cornus stolonifera Dogwood

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: up to 26.3 (Renault and Zwiazek 1997)

pH Tolerance Range: 5.12 (Renault et al. 1999); 5.3 (Renault et al. 1998a); 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Field Research - Syncrude U Shaped Cell (Study 97:2)

EC: 1.7 to 2.2 dS/m at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

SAR: 8.1 to 26.3 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

pH: 7.7 to 7.9 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

Notes: Seedlings were planted in CT material on the U-shaped cell at Syncrude in June 1997. All dogwood seedlings were alive after 2 months (Renault and Zwiazek 1997).

Dogwood seedlings showed new root and shoot growth after 2 months (Renault and Zwiazek 1997). The water potential indicated the plants were not under stress (Renault and Zwiazek 1997). Additional factors that could affect the seedlings growing in the U-shaped cell include wind, temperature, and irradiation stresses (Renault and Zwiazek 1997). In 1998, after one year, the dogwood seedlings had a survival rate of 93.9% (Renault et al. 1998).

Field Research - Capping Material

EC: 1.2 to 2.2 dS/m, $CaSO_4$ predominantly (HBT AGRA 1994).

SAR: 1.2 to 1.7 (Fair soils); 3.4 (Poor soils) $NaSO_4$ (HBT AGRA 1994).

pH: 7.4 to 7.5 (HBT AGRA 1994).

Notes: In 1990**,** HBT AGRA commenced research on aspen, jack pine, white spruce and dogwood growing on capped overburden at Syncrude (HBT AGRA 1994). Each of the four fertilized plots received seedlings of the same species, but the quality and depth of the capping material was different for each plot. Three plots have 'fair' quality capping material of 30, 50 and 70 cm thickness and 1 plot has 'poor' quality capping material of 70 cm thickness (HBT AGRA 1994). Soil suitability ratings were based on criteria from the Soil Quality Working Group (1987) for reclamation in Alberta (HBT AGRA 1994). The 'poor' soil had a heavier texture (HBT AGRA 1994) and a higher SAR compared to the 'fair' soils (Warner personal communication).

Three growing seasons after transplanting (1993), dogwood seedlings had 68% survival with most of the mortality occurring during the first winter (HBT AGRA 1994). The differences among treatments were not statistically significant (HBT AGRA 1994). The vegetation was measured again in 1996. All species appeared healthy and there was no statistical difference in tree growth between the 4 treatment plots (Warner personal communication). The differences among the plots may become apparent when the trees become mature and their roots extend into the overburden (Warner personal communication).

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;
- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;
- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away. Sixty dogwood seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997). Two months after planting, the dogwood seedlings survived the CT and FT treatments and after one year the survival was 100% (Renault and Zwiazek 1997). Shoot and root growth in dogwood significantly increased in the FT treatment (Renault and Zwiazek 1997). Transpiration, water potentials and diffusive resistance of 1996 seedlings were not affected by CT and FT 3 weeks and 2 months after treatment. After one year, the transpiration rates increased in dogwood in the FT treatment (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Syncrude CT Water

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault et al. 1999).

SAR: not available

pH: 5.3 in control Treatment A, 7.9 Treatment B, 8.0 Treatment C, 8.4 Treatment D and 8.4 Treatment E (Renault et al. 1999).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault et al. 1999).

Twenty-four 1 year old seedlings of dogwood were grown in a hydroponics system (Renault et al. 1999). Survival of dogwood seedlings after 4 weeks was 100% in all treatments (Renault et al. 1999). Shoot and root growth was reduced slightly in Treatment E, but some seedlings showed similar growth rates to control plants (Renault et al. 1999). No leaf necrosis was observed (Renault et al. 1999). Water potentials were not affected by the 4 week CT water treatments (Renault et al. 1999). Transpiration rates were significantly lower than the control after 4 weeks in Treatments C and E (Renault et al. 1999). Leaf diffusive resistance was significantly greater than the control after 4 weeks in Treatments C and E (Renault et al. 1999).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A, 6.97 Treatment B, 7.4 Treatment C, 7.39 Treatment D, 7.42 Treatment E and 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a). Twenty-four cuttings of dogwood were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all dogwood seedlings were alive. Leaf necrosis was not observed (Renault et al. 1998a). Water potentials were not affected in any treatments (Renault et al. 1998a). Transpiration rates were relatively high for dogwood, but there was no visible injury indicating a tolerance for high salt levels or a restriction of salt uptake by the roots (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a).

Literature Review - Salinity Tolerance

EC: < 2 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Ledum groenlandicum **Labrador tea**

EC Tolerance Range: 0.05 to 0.3 dS/m, undisturbed soil (Webster and Innes 1981)

SAR Tolerance Range: < 0.20, undisturbed soil (Webster and Innes 1981)

pH Tolerance Range: 4.2 to 5.0, undisturbed soil (Webster and Innes 1981)

Confidence Limit: data are inconclusive

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981). Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

In July 1978, approx. 95% of the total cover for Labrador tea died following the brine treatment with no leaching, gypsum or fertilizer enhancements. In August 1979, the percent dead of the total cover was 100% (Hettinger 1981).

Potentilla fruticosa Shrubby cinquefoil

EC Tolerance Range: 2.4 to 3.9 dS/m (McKenzie et al. 1994)

SAR Tolerance Range: not available

pH Tolerance Range: < 4.5 (Ziemkiewicz et al. 1978)

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: Mean of 2.4 to 9.9 dS/m (type of salt not available) (McKenzie et al. 1994).

SAR: not available

pH: not available

Notes: To determine the salinity tolerance of 28 trees and shrubs, research was conducted near Brooks, Alberta for 5 years (McKenzie et al. 1994). The research included four species normally found in the boreal forest: shrubby cinquefoil, white spruce, saskatoon and paper birch. Six plants of each species were transplanted in spring 1989 into soil with varying degrees of salinity determined by using an EM38 salinity meter (McKenzie et al. 1994). Of the 5 zones of salinity, the highest zone had a mean salinity of 9.9 dS/m (McKenzie et al. 1994). Growth of each plant was measured at the beginning and end of each growing season for height, diameter at the widest point in the canopy and diameter at the narrowest point, usually the base (McKenzie et al. 1994). Dead plants were replaced until the end of 1991 (McKenzie et al. 1994).

Shrubby cinquefoil had good salt tolerance when its growth in the 2 lowest saline zones (mean 2.4 and 3.9 dS/m) was compared to the 2 highest saline zones (mean 8.5 and 9.9 dS/m). The growth of shrubby cinquefoil decreased 5.1% per dS/m increase (McKenzie et al. 1994). The mortality of shrubby cinquefoil averaged less than 20% per year from 1990 to 1993 (McKenzie et al. 1994).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: < 4.5 (Ziemkiewicz et al. 1978)

Notes: Hardy BBT (1989) indicates shrubby cinquefoil has no specific tolerances noted from the literature, but is expected to be relatively intolerant of saline conditions. It has a high acid tolerance and can tolerate soils with pH below 4.5 (Ziemkiewicz et al. 1978). It is sometimes found occurring naturally in acid bogs (Alaska Rural Development Council 1977). Also found on calcareous substrata (Peterson and Etter 1970, Elkington and Woodell 1963).

Prunus virginiana **Chokecherry**

EC Tolerance Range: 1.05 to 4.44 dS/m (Renault and Zwiazek 1997)

SAR Tolerance Range: not available

pH Tolerance Range: not available

Confidence Limit: data are inconclusive

Greenhouse Hydroponics Research - Suncor CT Water (Study 97:8)

EC: 1.047 dS/m in control (Treatment A) (deionized water only); 1.455 dS/m with 25% CT water (Treatment B); 1.958 dS/m with 50% CT water (Treatment C); 2.958 dS/m with 100% CT water (Treatment D) and 4.44 dS/m with 100% CT water and 1420 ppm $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997).

SAR: not available

pH: not available

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997). Twenty-four seedlings of chokecherry were grown in a hydroponics system (Renault and Zwiazek 1997). All chokecherry seedlings survived the 4 week CT treatments (Renault and Zwiazek 1997). Leaf necrosis and inhibition of root growth was observed in treatments of 50% and 100% CT water (Renault and Zwiazek 1997). Chokecherry seedlings lost their leaves and then grew new ones (Renault and Zwiazek 1997). Water potentials were not affected by CT treatments (Renault and Zwiazek 1997). Transpiration rates in 50% CT water decreased initially, but after 4 weeks, the transpiration rates were similar to the control indicating the chokecherry plants had adapted to CT water (Renault and Zwiazek 1997).

Literature Review - Salinity Tolerance

EC: > 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for “low”, 1,500 to 3,000 ppm for “moderate” and > 3000 ppm for “high” (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985).

Rosa acicularis Prickly rose

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 6.1 dS/m; $\pm$ 1 standard deviation: 1.3 to 10.9 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.5, range 7.2 to 7.8 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991).

The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Prickly rose and snowberry belong to the Rosa association, which is the only one in which shrubs commonly occur (Burchill and Kenkel 1991).

Rosa woodsii **Rose**

EC Tolerance Range: 0.98 to 7.910 dS/m (Renault and Zwiazek 1997)

SAR Tolerance Range: unknown

pH Tolerance Range: 5.26 to 8.41 (Renault and Zwiazek 1997)

Confidence Limit: data are inconclusive

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;
- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;
- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away. Sixty rose seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997). Rose seedling survival rates were low and physiological parameters were not measured. The rose seedlings wilted rapidly and lost foliage and very few plants recovered and resumed growth in any of the treatments (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Syncrude CT Water (Study 97:8)

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault and Zwiazek 1997).

SAR: not available

pH: 5.26 in control Treatment A, 7.9 Treatment B, 8.04 Treatment C, 8.41 Treatment D and 8.35 Treatment E (Renault and Zwiazek 1997).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault and Zwiazek 1997).

Twenty-four seedlings of rose were grown in a hydroponics system (Renault and Zwiazek 1997). Survival of rose seedlings after 4 weeks was 100% in all treatments except for Treatment E at 87.5% survival (Renault and Zwiazek 1997). Shoot and root growth was reduced in Treatments D and E (Renault and Zwiazek 1997). Leaf necrosis was observed in all seedlings after 4 weeks (Renault and Zwiazek 1997). Water potentials were not significantly affected by the 4 week CT water treatments (Renault and Zwiazek 1997). Transpiration rates were not significantly different than the control after 4 weeks in any treatment (Renault and Zwiazek 1997). Leaf diffusive resistance was not significantly different than the control after 4 weeks in any treatment (Renault and Zwiazek 1997).

Rubus idaeus Raspberry

EC Tolerance Range: 1.03 to 2.030 dS/m (Renault et al. 1998a)

SAR Tolerance Range: not available

pH Tolerance Range: 4.8 (Schlatzer 1973); 5.12 to 7.4 (Renault et al. 1998a)

Confidence Limit: data are inconclusive

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;
- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;
- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away. Sixty raspberry seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997). Raspberry survival rates were low and physiological parameters were not measured. The seedlings wilted rapidly and lost foliage and very few plants recovered and resumed growth in any of the treatments (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A; 6.97 Treatment B; 7.4 Treatment C; 7.39 Treatment D; 7.42 Treatment E and; 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four 2 month old seedlings of raspberry were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all raspberry seedlings were alive in the control and Treatment B, but only 25% were alive in Treatment C and 0% survived in Treatments D, E and F (Renault et al. 1998a). Leaf necrosis was observed in Treatment D (Renault et al. 1998a). Water potentials declined rapidly in Treatments C, D, E and F (Renault et al. 1998a). Transpiration rates were reduced compared to the control in Treatments E and F (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 4.8 (Schlatzer 1973)

Notes: Hardy BBT (1989) indicates raspberry will probably tolerate moderate salinity. It has a moderate acid tolerance (Alaska Rural Development Council 1977). It has been found on previously barren acid tailings sands that has been ameliorated with lime. This vegetation later deteriorated as the soil acidity increased again (from pH 4.8 to 3.9) (Schlatzer 1973).

Salix alaxensis **Alaska willow**

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Salix brachycarpa **Short-capsuled willow**

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Salix nova-anglaea Low blueberry willow

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Shepherdia canadensis **Buffaloberry**

EC Tolerance Range: 0.98 to 7.910 dS/m (Renault et al. 1999)

SAR Tolerance Range: not available

pH Tolerance Range: 5.3 to 8.4 (Renault et al. 1999)

Confidence Limit: data are inconclusive

Greenhouse Hydroponics Research - Syncrude CT Water

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault et al. 1999).

SAR: not available

pH: 5.3 in control Treatment A, 7.9 Treatment B, 8.0 Treatment C, 8.4 Treatment D and 8.4 Treatment E (Renault et al. 1999).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault et al. 1999).

Twenty-four 8 month old seedlings of buffaloberry were grown in a hydroponics system (Renault et al. 1999). Survival of buffaloberry seedlings after 4 weeks was 100% in all treatments (Renault et al. 1999). Shoot and root growth was not affected in any treatment (Renault et al. 1999). Leaf necrosis was observed in all seedlings after 4 weeks (Renault et al. 1999). Water potential was significantly greater after 4 weeks in Treatment C (Renault et al. 1999). Transpiration rates were significantly lower than the control after 4 weeks Treatments B, C, D and E (Renault et al. 1999). Leaf diffusive resistance was significantly greater than the control after 4 weeks in Treatments D and E (Renault et al. 1999).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 8.0 to 8.4 (Peterson and Peterson 1977)

Notes: Hardy BBT (1989) indicates buffaloberry can tolerate moderately alkaline (pH 8.0 to 8.4) to moderately acidic soils (Peterson and Peterson 1977).

Symphoricarpos albus Snowberry

EC Tolerance Range: 1.3 to 10.9 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 7.8 (Burchill and Kenkel 1991)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 6.1 dS/m; ± 1 standard deviation: 1.3 to 10.9 dS/m (type of salts not provided) (Burchill and Kenkel 1991).

SAR: not available

pH: mean 7.5, range 7.2 to 7.8 (Burchill and Kenkel 1991).

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Snowberry and prickly rose belong to the Rosa association, which is the only one in which shrubs commonly occur (Burchill and Kenkel 1991).

Vaccinium myrtilloides Blueberry

EC Tolerance Range: 0.05 to 0.3 dS/m, undisturbed soil (Webster and Innes 1981)

SAR Tolerance Range: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981)

pH Tolerance Range: 4.2 to 5.0, undisturbed soil (Webster and Innes 1981)

Confidence Limit: data are inconclusive

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981) Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

In July 1978, approx. 100% of the total cover for blueberry died following the brine treatment with no leaching, gypsum or fertilizer enhancements (Hettinger 1981).

Virburnum edule Low-bush cranberry

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: < 0.20, undisturbed soil (Webster and Innes 1981)

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981) Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

In July 1978, approx. 100% of the total cover for low-bush cranberry was severely damaged following the brine treatment with no leaching, gypsum or fertilizer enhancements. In September 1978, the percent severely damaged of the total cover remained at 100% (Hettinger 1981).

9.4 Trees

Abies balsamea Balsam fir

EC Tolerance Range: 0.05 to 0.3 dS/m, undisturbed soil (Webster and Innes 1981)

SAR Tolerance Range: < 0.20, undisturbed soil (Webster and Innes 1981)

pH Tolerance Range: 4.2 to 5.0, undisturbed soil (Webster and Innes 1981)

Confidence Limit: data are inconclusive

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981) Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

Balsam fir seedlings had approx. 95% mortality in July 1978 and 100% mortality in August 1979 (Hettinger 1981). Mortality is defined for conifers as trees with an estimated 90% or more brown needles (Hettinger 1981). No mature balsam fir trees were at the site.

Literature Review - Salinity Tolerance

EC: < 2 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for “low”, 1,500 to 3,000 ppm for “moderate” and > 3000 ppm for “high” (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report’s author.

Betula papyrifera Paper birch

EC Tolerance Range: 2.4 to < 6.4 dS/m (McKenzie et al. 1994)

SAR Tolerance Range: not available

pH Tolerance Range: 3.2 to 4.4 (Balsillie et al. 1978)

Confidence Limit: data are inconclusive

Field Research - Salinity Tolerance

EC: Mean of 2.4 to 9.9 dS/m (type of salt not available) (McKenzie et al. 1994).

SAR: not available

pH: not available

Notes: To determine the salinity tolerance of 28 trees and shrubs, research was conducted near Brooks, Alberta for 5 years (McKenzie et al. 1994). The research included four species normally found in the boreal forest: shrubby cinquefoil, white spruce, saskatoon and paper birch. Six plants of each species were transplanted in spring 1989 into soil with varying degrees of salinity determined by using an EM38 salinity meter (McKenzie et al. 1994). Of the 5 zones of salinity, the highest zone had a mean salinity of 9.9 dS/m (McKenzie et al. 1994). Growth of each plant was measured at the beginning and end of each growing season for height, diameter at the widest point in the canopy and diameter at the narrowest point, usually the base (McKenzie et al. 1994). Dead plants were replaced until the end of 1991 (McKenzie et al. 1994).

Paper birch had a high average yearly mortality rate of 73% in the medium to high salinity zones (mean 6.4 to 9.9 dS/m) (McKenzie et al. 1994). The growth of paper birch decreased 12.5% per dS/m increase, which was the greatest decrease of any species (McKenzie et al. 1994).

Literature Review - Salinity Tolerance

EC: 2 to 4 dS/m for birch species (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for “low”, 1,500 to 3,000 ppm for “moderate” and > 3000 ppm for “high” (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report’s author.

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 3.2 to 4.4 (Balsillie et al. 1978)

Notes: Hardy BBT (1989) indicates paper birch has moderate acid tolerance (Alaska Rural Development Council 1977) and it has also been observed growing in semi-barren soils which are very acid (pH 3.2 to 4.4) (Balsillie et al. 1978).

Picea glauca White spruce

EC Tolerance Range: 8.75 to 14.92 dS/m (Yarie et al. 1993)

SAR Tolerance Range: 0 to 26.3 (Renault and Zwiazek 1997)

pH Tolerance Range: 3.9 (Mitchell and Kay 1973); 5.12 (Renault et al. 1998a); 6.64 to 10.94 (Maynard et al. 1997)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed Site

EC: soil-solution: 8.75 to 14.92 dS/m at 50 cm; 7.15 to 14.59 dS/m at 150 cm; groundwater: 7.84 to 10.11 dS/m Stage VIII sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.7 to 8.7 at 50 cm; 7.4 to 7.8 at 150 cm; groundwater pH 7.2 to 8.0 Stage VIII sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage VIII (Yarie et al. 1993).

Field Research - Capping Material

EC: 1.2 to 2.2 dS/m, $CaSO_4$ predominantly (HBT AGRA 1994).

SAR: 1.2 to 1.7 (Fair soils); 3.4 (Poor soils) $NaSO_4$ (HBT AGRA 1994).

pH: 7.4 to 7.5 (HBT AGRA 1994).

Notes: In 1990**,** HBT AGRA commenced research on aspen, jack pine, white spruce and dogwood growing on capped overburden at Syncrude (HBT AGRA 1994). Each of the four fertilized plots received seedlings of the same species, but the quality and depth of the capping material was different for each plot. Three plots have 'fair' quality capping material of 30, 50 and 70 cm thickness and 1 plot has 'poor' quality capping material of 70 cm thickness (HBT AGRA 1994). Soil suitability ratings were based on criteria from the Soil Quality Working Group (1987) for reclamation in Alberta (HBT AGRA 1994). The 'poor' soil had a heavier texture (HBT AGRA 1994) and a higher SAR compared to the 'fair' soils (Warner personal communication).

Three growing seasons after transplanting (1993), white spruce seedlings had 96% survival and the differences among treatments were not statistically significant (HBT AGRA 1994). The vegetation was measured again in 1996. All species appeared healthy and there was no statistical difference in tree growth between the 4 treatment plots (Warner, personal communication). The differences among the plots may become apparent when the trees become mature and their roots extend into the overburden (Warner, personal communication).

Field Research - Salinity Tolerance

EC: Mean of 2.4 to 9.9 dS/m (type of salt not available)(McKenzie et al. 1994).

SAR: not available

pH: not available

Notes: To determine the salinity tolerance of 28 trees and shrubs, research was conducted near Brooks, Alberta for 5 years (McKenzie et al. 1994). The research included four species normally found in the boreal forest: shrubby cinquefoil, white spruce, saskatoon and paper birch. Six plants of each species were transplanted in spring 1989 into soil with varying degrees of salinity determined by using an EM38 salinity meter (McKenzie et al. 1994). Of the 5 zones of salinity, the highest zone had a mean salinity of 9.9 dS/m (McKenzie et al. 1994). Growth of each plant was measured at the beginning and end of each growing season for height, diameter at the widest point in the canopy and diameter at the narrowest point, usually the base (McKenzie et al. 1994). Dead plants were replaced until the end of 1991 (McKenzie et al. 1994). White spruce had a high average yearly mortality rate of approximately 45% in the medium-high to high salinity zones (mean 8.5 to 9.9 dS/m) (McKenzie et al. 1994). The growth of white spruce decreased 9.0% per dS/m increase (McKenzie et al. 1994).

Field Research - Syncrude U Shaped Cell (Study 97:2)

EC: 1.7 to 2.2 dS/m at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

SAR: 8.1 to 26.3 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

pH: 7.7 to 7.9 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

Notes: Seedlings were planted in CT material on the U-shaped cell at Syncrude in June 1997. All spruce seedlings were alive after 2 months (Renault and Zwiazek 1997). The white spruce seedlings were partially buried under the sand, but only a few seedlings were observed with needle necrosis two months after planting (Renault and Zwiazek 1997). Wind, temperature and irradiation stresses could also stress seedlings and affect research results (Renault and Zwiazek 1997). The water potential for white spruce seedlings indicated they were not under stress or had low transpiration rates which would limit the uptake of ions (Renault and Zwiazek 1997). White spruce and dogwood performed better in this research than northwest hybrid poplar, aspen and peachleaf willow (Renault and Zwiazek 1997).

In 1998, after one year, the white spruce seedlings had a survival rate of 22.7% (Renault et al. 1998). Many white spruce seedlings were buried under the sand (Renault et al. 1998).

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;
- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;
- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away. A few white spruce seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997 Renault and Zwiazek (1997) (Study 5) observed needle necrosis on white spruce seedlings in all treatments, but one year after planting, the survival rate was 100%. The two month exposure treatment did not affect shoot and root growth of white spruce seedlings (Renault and Zwiazek 1997). The water potentials, transpiration and diffusive resistance were not affected by the presence of CT and FT when measured three weeks and two months after treatment (Renault and Zwiazek 1997).

Field Research - Brine Spill

EC: Spill site: 5.85 dS/m at LFH (7.5 to 0 cm); 5.09 dS/m at Aej (0 to 5 cm); 4.07 dS/m at AB (5 to 30 cm); 1.79 dS/m at Bt1 (30 to 60 cm) with Ca, Na and Cl increasing most significantly compared to control (Edwards and Blauel 1975). Control site: EC < 1.00 dS/m throughout profile (Edwards and Blauel 1975).

SAR: Spill site: 12.75 at LFH (7.5 to 0 cm); 11.89 at Aej (0 to 5 cm); 8.45 at AB (5 to 30 cm); 3.12 at Bt1 (30 to 60 cm); 7.92 at Bt2 (60 to 75 cm). Control site: 2.36 at LFH (7.5 to 0 cm); 3.64 at Aej (0 to 5 cm); 3.02 at AB (5 to 30 cm); 3.95 at Bt1 (30 to 60 cm); 4.77 at Bt2 (60 to 75 cm). (Edwards and Blauel 1975).

pH: Spill site: 6.3 at LFH (7.5 to 0 cm); 5.8 at Aej (0 to 5 cm); 6.4 at AB (5 to 30 cm); 7.0 at Bt1 (30 to 60 cm); 7.3 at Bt2 (60 to 75 cm). Control site: 4.3 at LFH (7.5 to 0 cm); 4.4 at Aej (0 to 5 cm); 4.6 at AB (5 to 30 cm); 4.5 at Bt1 (30 to 60 cm); 4.9 at Bt2 (60 to 75 cm). (Edwards and Blauel 1975).

Notes: Swan Hills Site 19 was examined and sampled for changes in the Orthic Gray Luvisolic soil and vegetation following a brine spill in June 1973 (Edwards and Blauel 1975). Samples of the actual spill water were not obtained, but brine samples from storage tanks contained mainly sodium (22,400 mg/l) and chloride (34,600 mg/l) approximately double the concentration found in sea water (Edwards and Blauel 1975). There were 4 subplots at Site 19 with varying concentrations of Cl at 30 cm measured in August 1973: at 5,502 ppm Cl severe discoloration of spruce needles; at 62,568 ppm Cl many dead trees, few survivors were severely stressed; at 9,940 ppm Cl trees dead by September 1974; at maximum concentration of 520 ppm Cl in September 1974, there was a light level of foliar discoloration, by September 1975 (290 ppm) the white spruce had a normal appearance (Edwards and Blauel 1975).

Greenhouse Hydroponics Research - Saline Water

EC: 1.016 dS/m in control; 25mM NaCl, 3.13 dS/m (Treatment A); 50 mM NaCl, 6.33 dS/m (Treatment B); 75 mM NaCl, 8.80 dS/m (Treatment C) and; CT water from Syncrude, 4.10 dS/m (Treatment D) (Khasa and Hambling, personal communication).

SAR: not available

pH: 6.96 Control; 6.93 Treatment A; 6.94 Treatment B; 6.94 Treatment C; 8.06 Treatment D (Khasa and Hambling, personal communication).

Notes: Woody species were grown hydroponically in the greenhouse to determine their salt tolerance (Khasa and Hambling, personal communication). All treatments were made with 0.5% Hoagland's solution and the addition of salt or water (Khasa and Hambling, personal communication). There were 12 white spruce seedlings in each treatment (Khasa and Hambling, personal communication). Exposure to the treatment commenced when the seedlings were 1 to 2 months old and lasted 1 month (Khasa and Hambling, personal communication). The seedlings were observed for chlorosis and survival after 1 month of exposure.

In the control, no white spruce seedlings developed chlorosis (Khasa and Hambling, personal communication). In Treatment A (3.13 dS/m), 1 white spruce died, 1 had light chlorosis and the remainder had none (Khasa and Hambling, personal communication). In Treatment B (6.33 dS/m), 1 seedling died, I had severe chlorosis, 1 had moderate chlorosis, 2 had light chlorosis and 7 had no chlorosis (Khasa and Hambling, personal communication). In the highest saline treatment, Treatment C (8.80 dS/m), 6 seedlings died, 3 had severe chlorosis, 1 had moderate chlorosis and 2 did not develop chlorosis (Khasa and Hambling, personal communication). In the CT water treatment (4.10 dS/m), 2 seedlings died, 4 seedlings had light chlorosis and the remainder had no observable effects (Khasa and Hambling, personal communication).

Greenhouse Research - Watering with Sodium Carbonate - Enriched Water

EC: 0 to 3.1 dS/m water enriched with Na_2CO_3 (Maynard et al. 1997). After fertilizing the EC was 1.29 to 3.42 dS/m (Maynard et al. 1997).

SAR: not available.

pH: 6.64 to 10.94, increasing with the increase in EC (Maynard et al. 1997). After fertilizing the pH was 5.25 to 10.22 dS/m (Maynard et al. 1997).

Notes: Soil material consisted of sphagnum peat, perlite, calcium carbonate soaked with a solution of Na_2CO_3 at 0.0, 0.5, 1.0, 1.7, and 3.1 dS/m corresponding to a pH of 6.64, 10.24, 10.50, 10.72 and 10.94 (Maynard et al. 1997). Seeded trays were misted with corresponding salt solutions. Approximately 5 weeks after germination, the seedlings were watered with the corresponding salt solution and fertilizer twice per week. The fertilizing regime was the same as for a local grower of spruce (Maynard et al. 1997). The EC increased after fertilization to 1.29, 1.48, 1.65, 2.15, and 3.42 dS/m corresponding to pH values of 5.25, 7.18, 8.16, 9.65 and 10.22 (Maynard et al. 1997).

The EC indicated in the following results are the pre-fertilization EC values. The 0.5 dS/m treatment had 8% poorer emergence and decreased survival and reduced growth compared to seedlings in the 0.0 dS/m control treatment (Maynard et al. 1997). Emergence was approximately 30% in the 3.1 dS/m treatment and 55% in the 1.7 dS/m treatment (Maynard et al. 1997). After 12 weeks of growth, survival was 5% lower in the 0.5 dS/m treatment compared to the 0.0 dS/m control (Maynard et al. 1997). After 12 weeks at 3.1 dS/m, the survival was approximately 10%, compared to the 1.7 dS/m treatment at nearly 80% survival (Maynard et al. 1997). Nutrient deficiencies were not a factor (Maynard et al. 1997). Height, basal stem diameter and foliage weight were also decreased (Maynard et al. 1997). Excess Na+ may have been responsible for the reduced plant growth and the increasing EC may have resulted in growth reductions (Maynard et al. 1997).

Greenhouse Hydroponics Research - Syncrude CT Water

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault et al. 1999).

SAR: not available

pH: 5.3 in control Treatment A; 7.9 Treatment B; 8.0 Treatment C; 8.4 Treatment D and; 8.4 Treatment E (Renault et al. 1999).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault et al. 1999).

Twenty-four 2 year old seedlings of white spruce were grown in a hydroponics system (Renault et al. 1999). After 4 weeks, all white spruce seedlings were alive. In Treatment E, the seedlings still had a few green needles and were recorded as living (Renault et al. 1999). However, if the treatment was extended for a few more days, the seedlings would have likely died (Renault et al. 1999). Needle necrosis was observed in all CT treatments, but not all white spruce seedlings were affected to the same degree (Renault et al. 1999). Due to this variability, none of the CT treatments significantly affected the water potentials except for an insignificant decline in Treatment E compared to the control (Renault et al. 1999). Transpiration rates were significantly lower than the control after 4 weeks for Treatments C, D and E (Renault et al. 1999). Leaf diffusive resistance was not significantly greater in any treatments after 4 weeks (Renault et al. 1999).

Greenhouse Research - Suncor and Syncrude CT Water (Study 97:9)

EC: 0.0205 dS/m in control (deionized water). Sixteen treatments with NaCl, $NaSO_4$, Syncrude CT water at different proportions, Suncor CT water at different proportions, and 100% CT water plus $NaSO_4$ and/or NaCl (Renault et al. 1998b). EC values range from 0.947 dS/m to >20.00 dS/m (Renault et al. 1998b).

SAR: not available

pH: not available

Notes: Germination of coniferous species in 16 various treatment solutions and survival after 6 weeks. White spruce had a significant reduction in germination at EC 11.360 dS/m (100 mM $NaSO_4$) and 3.840 dS/m (50 mM NaCl) and in Syncrude CT water with 10 mM $NaSO_4$ and 10 mM NaCl (EC 5.040 dS/m) (Renault et al. 1998b). Among jack pine, black spruce and white spruce, white spruce was the most sensitive to the salts (Renault et al. 1998b).

After 6 weeks, 76.5% of seedlings survived in the control, compared to 14.6% survival in the 100 mM $NaSO_4$ treatment (EC 11.360 dS/m) and 75% survival in the 10 mM $NaSO_4$ (EC 1.518 dS/m) (Renault et al. 1998b). Percentage of plants with needle necrosis was 8.2% in the control, and ranged from 4.0% (10mM NaCl; 0.947 dS/m) to 16.6% (10 mM $NaSO_4$; 1.518 dS/m) (Renault et al. 1998). The most severe CT treatment, the Syncrude CT water with 10 mM $NaSO_4$ and 10 mM NaCl treatment (5.04 dS/m), had a 6 week survival rate of 63.8% and needle necrosis in 14.5% of plants (Renault et al. 1998b). There was a reduction in fresh weight with an increase in salt concentration and greater reduction in root compared to shoot length with an increase in salt concentration (Renault et al. 1998b).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A; 6.97 Treatment B; 7.4 Treatment C; 7.39 Treatment D; 7.42 Treatment E and; 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four 8 month old seedlings of white spruce were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all white spruce seedlings were alive. Needle necrosis was observed in the 100% CT treatment (Renault et al. 1998a). The water potentials decreased in 25% and higher concentrations of CT (Renault et al. 1998a). Transpiration rates were lower than the control after 4 weeks for Treatments E and F (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a). In the highest salt concentrations, not in all white spruce seedlings had needle necrosis or changes in water potentials, which suggests a high degree of individual resistance within the species (Renault et al. 1998a).

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 3.9 (Mitchell and Kay 1973)

Notes: Hardy BBT (1989) indicates white spruce is intolerant of saline conditions (Kagis 1965). It has a high acid tolerance (Alaska Rural Development Council 1977). The lower pH limit for white spruce has been reported to be 4.5 to 5.0 (Rafaill and Vogel 1978). However, seedlings grown in peat with pH adjusted (lime additives) from 3.9 upward to 5.0 had half the total weight and root weight of seedlings grown in peat of pH 3.9 (Mitchell and Kay 1973).

Picea mariana **Black spruce**

EC Tolerance Range: 0.21 to 7.110 dS/m (Renault et al. 1998b)

SAR Tolerance Range: unknown, < 0.20, undisturbed soil (Webster and Innes 1981)

pH Tolerance Range: 5.26 to 8.41 (Renault and Zwiazek 1997)

Confidence Limit: data are inconclusive

Field Research - Brine Spill

EC: 0.05 to 0.3 dS/m, 0 to 90 cm, undisturbed soil (Webster and Innes 1981) Following brine spill June 1, 1978, EC increased to approx. 5.5 dS/m, 0 to 30 cm then decreased to approx. 1 dS/m at 0 to 30 cm depth, by mid-October 1978. EC remained near 1 dS/m throughout 1979. At 0 to 60 cm depth, EC increased to a maximum of approx. 4.2 dS/m in early June 1978, then decreased to less than 2 dS/m by mid-October 1978. In 1979, it was less than 1 dS/m at 0 to 60 cm from June to November (Webster and Innes 1981).

SAR: < 0.20, 0 to 30 cm depth, undisturbed soil (Webster and Innes 1981). SAR was 8.17 in 1978 and 4.99 in 1979 at 0 to 30 cm depth (Webster and Innes 1981). No data was provided for depths greater than 30 cm.

pH: 4.2 to 5.0, 0 to 91 cm depth, undisturbed soil (Webster and Innes 1981). Approx. 4.7 to 5.1, 0 to 30 cm depth, approx. 3.5 to 4.8, 30 to 91 cm depth, following brine spill (Webster and Innes 1981).

Notes: Webster and Innes (1981) conducted several experiments in the boreal forest near Swan Hills, Alberta in 1978 and 1979. The control treatment is the source for undisturbed data and the treatment that received brine with no subsequent leaching or gypsum to reduce the brine concentration is used for post disturbance measurements. Main constituents of brine were Na (13, 100 mg/L and Cl (24,000 mg/L). Brine also contained boron (39 mg/L), cobalt (4.21 mg/L), iron (1.23 mg/L), nickel (4.64 mg/L), vanadium (1.55 mg/L) and zinc (0.21 mg/L) in levels higher than specified by surface water quality criteria, but specific criteria were not provided (Webster and Innes 1981).

The total ground cover of black spruce prior to the spill was 1% (mean cover) and the quadrat frequency was 50% (12 quadrats, each 0.5 x 1.0 m) (Hettinger 1981). In July 1978, 94.5% of the total cover was severely damaged following the brine treatment with no leaching, gypsum or fertilizer enhancements. In August 1979, the percent severely damaged of the total cover was 94% (Hettinger 1981).

Greenhouse Hydroponics Research - Syncrude CT Water (Study 97:8)

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault and Zwiazek 1997).

SAR: not available

pH: 5.26 in control Treatment A; 7.9 Treatment B; 8.04 Treatment C; 8.41 Treatment D and; 8.35 Treatment E (Renault and Zwiazek 1997).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault and Zwiazek 1997).

Twenty-four seedlings of black spruce were grown in a hydroponics system (Renault and Zwiazek 1997). After 4 weeks, black spruce seedlings had survival rates of 100% in all treatments except for Treatment E (Renault and Zwiazek 1997). Needle necrosis and stunted root development was observed in all CT treatments (Renault and Zwiazek 1997). However, some black spruce seedlings were not affected by the CT water to the same extent as others even in the presence of 100% CT water (Renault and Zwiazek 1997). None of the CT water treatments significantly affected the water potentials of black spruce seedlings except for a insignificant decrease in Treatment E compared to the control (Renault and Zwiazek 1997). Transpiration rates were not significantly different in any treatments after 4 weeks (Renault and Zwiazek 1997). Leaf diffusive resistance was not significantly different in any treatments after 4 weeks (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A; 6.97 Treatment B; 7.4 Treatment C; 7.39 Treatment D; 7.42 Treatment E and; 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four 8 month old seedlings of black spruce were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all black spruce seedlings were alive. Needle necrosis was not observed (Renault et al. 1998a). Water potentials were not affected in any treatment (Renault et al. 1998a). Transpiration rates were lower than the control after 4 weeks for Treatments E and F (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a).

Greenhouse Research - Suncor and Syncrude CT Water (Study 97:9)

EC: 0.0205 dS/m in control (deionized water). Sixteen treatments with NaCl, $NaSO_4$, Syncrude CT water at different proportions, Suncor CT water at different proportions, and 100% CT water plus $NaSO_4$ and/or NaCl (Renault et al. 1998b). EC values range from 0.947 dS/m to >20.00 dS/m (Renault et al. 1998b).

SAR: not available

pH: not available

Notes: Germination of coniferous species in 16 various treatment solutions and survival after 6 weeks. Black spruce had a significant reduction in germination at EC 11.360 dS/m (100 mM $NaSO_4$) and 7.710 dS/m (100 mM NaCl) (Renault et al. 1998b). Among jack pine, black spruce and white spruce, white spruce was the most sensitive to the salts (Renault et al. 1998b).

After 6 weeks, 94% of seedlings survived in the control, compared to 12.5% survival in the 100 mM NaCl treatment (EC 7.710 dS/m) and 91.5% survival in the 10 mM NaCl treatment (EC 0.947 dS/m) (Renault et al. 1998b). Percentage of plants with needle necrosis was 7.0% in the control, and ranged from 1.7% (100% Suncor CT water; 1.637 dS/m) to 21.8% (20 mM $NaSO_4$; 2.890 dS/m) (Renault et al. 1998b). The most severe CT treatment, the Syncrude CT water with 10 mM $NaSO_4$ and 10 mM NaCl treatment (EC 5.040 dS/m), had a 6 week survival rate of 77% and needle necrosis in 15.8% of plants (Renault et al. 1998b). There was a reduction in fresh weight with an increase in salt concentration and greater reduction in root compared to shoot length with an increase in salt concentration (Renault et al. 1998b).

Literature Review - Salinity Tolerance

EC: >4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for “low”, 1,500 to 3,000 ppm for “moderate” and

> 3000 ppm for “high” (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report’s author.

Pinus banksiana **Jack pine**

EC Tolerance Range: 1.02 to 6.33 dS/m (Khasa and Hambling, personal communication)

SAR Tolerance Range: 0 to 7.2 (Renault and Zwiazek 1997)

pH Tolerance Range: 3.5 (Hardy BBT 1989); 5.3 to 8.4 (Renault et al. 1999)

Confidence Limit: data are inconclusive

Field Research - Capping Material

EC: 1.2 to 2.2 dS/m, $CaSO_4$ predominantly (HBT AGRA 1994).

SAR: 1.2 to 1.7 (Fair soils); 3.4 (Poor soils) $NaSO_4$ (HBT AGRA 1994).

pH: 7.4 to 7.5 (HBT AGRA 1994).

Notes: In 1990**,** HBT AGRA commenced research on aspen, jack pine, white spruce and dogwood growing on capped overburden at Syncrude (HBT AGRA 1994). Each of the four fertilized plots received seedlings of the same species, but the quality and depth of the capping material was different for each plot. Three plots have 'fair' quality capping material of 30, 50 and 70 cm thickness and 1 plot has 'poor' quality capping material of 70 cm thickness (HBT AGRA 1994). Soil suitability ratings were based on criteria from the Soil Quality Working Group (1987) for reclamation in Alberta (HBT AGRA 1994). The 'poor' soil had a heavier texture (HBT AGRA 1994) and a higher SAR compared to the 'fair' soils (Warner personal communication).

Three growing seasons after transplanting (1993), jack pine seedlings had a 78% survival (HBT AGRA 1994). Survival ranged from 59% in the 50 cm 'fair' treatment to 91% in the 'poor' treatment and survival in the 50 cm 'fair' treatment was significantly lower than the two best treatments (30 cm 'fair' and 70 cm 'poor') (HBT AGRA 1994). Survival in the 70 cm 'fair' treatment was intermediate at 73% (HBT AGRA 1994). The vegetation was measured again in 1996. All species appeared healthy and there was no statistical difference in tree growth between the 4 treatment plots (Warner, personal communication). The differences among the plots may become apparent when the trees become mature and their roots extend into the overburden (Warner, personal communication).

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;

- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;

- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away.

A few jack pine seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997). Jack pine showed needle necrosis in all treatments (Renault and Zwiazek 1997). One year after planting the survival rate of jack pine was 100% (Renault and Zwiazek 1997). The physiological parameters of jack pine were not affected by the treatments when examined after 3 weeks and again after 2 months (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Syncrude CT Water

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault et al. 1999).

SAR: not available

pH: 5.3 in control Treatment A; 7.9 Treatment B; 8.0 Treatment C; 8.4 Treatment D and; 8.4 Treatment E (Renault et al. 1999).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault et al. 1999).

Twenty-four 8 month old seedlings of jack pine were grown in a hydroponics system (Renault et al. 1999). After 4 weeks, jack pine seedlings had survival rates of 83% (Treatments B, C and D) and 17% (Treatment E) (Renault et al. 1999). Needle necrosis and stunted root development was observed in all CT treatments (Renault et al. 1999). None of the CT water treatments significantly affected the water potentials of jack pine seedlings except for an insignificant decrease in Treatment E compared to the control (Renault et al. 1999). Transpiration rates were significantly lower than the control after 4 weeks for Treatments D and E (Renault et al. 1999). Leaf diffusive resistance was not significantly greater in any treatments after 4 weeks (Renault et al. 1999).

Greenhouse Research - Suncor and Syncrude CT Water (Study 97:9)

EC: 0.0205 dS/m in control (deionized water). Sixteen treatments with NaCl, $NaSO_4$, Syncrude CT water at different proportions, Suncor CT water at different proportions, and 100% CT water plus $NaSO_4$ and NaCl or $NaSO_4$ (Renault et al. 1998b). EC values range from 0.947 dS/m to >20.00 dS/m (Renault et al. 1998b).

SAR: not available

pH: not available

Notes: Germination of coniferous species in 16 various treatment solutions and survival after 6 weeks. Jack pine tolerated the highest level of salt and germinated at reduced levels when salt concentrations reached 100 mM concentration (100 mM NaCl, 7.710 dS/m; 100 mM $NaSO_4$, 11.360 dS/m) (Renault et al. 1998b). Among jack pine, black spruce and white spruce, white spruce was the most sensitive to the salts (Renault et al. 1998b).

After 6 weeks, 77.5% of seedlings survived in the control, compared to 28.1% survival in the 100 mM NaCl treatment (EC 7.710 dS/m) and 88.4% survival in the 50% Syncrude CT water treatment (EC 1.840 dS/m) (Renault et al. 1998b). Percentage of jack pine seedlings with needle necrosis was 9.2% in the control, and ranged from 5.7% (10 mM NaCl; 0.947 dS/m) to 46.3% (100 mM NaCl; 7.710 dS/m) (Renault et al. 1998b). The most severe CT treatment, the Syncrude CT water with 10 mM $NaSO_4$ and 10 mM NaCl treatment (EC 5.040 dS/m), had a 6 week survival rate of 69.5% and needle necrosis in 20.9% of plants (Renault et al. 1998b). Jack pine had the highest levels of needle necrosis and needle damage increased with the increase in salt concentration unlike white spruce and black spruce (Renault et al. 1998b). Jack pine seedlings had a reduction in fresh weight with an increase in salt concentration and greater reduction in root compared to shoot length with an increase in salt concentration (Renault et al. 1998b).

Greenhouse Hydroponics Research - Saline Water

EC: 1.016 dS/m in control; 25mM NaCl, 3.13 dS/m (Treatment A); 50 mM NaCl, 6.33 dS/m (Treatment B); 75 mM NaCl, 8.80 dS/m (Treatment C) and; CT water from Syncrude, 4.10 dS/m (Treatment D) (Khasa and Hambling, personal communication).

SAR: not available

pH: 6.96 Control; 6.93 Treatment A; 6.94 Treatment B; 6.94 Treatment C; 8.06 Treatment D (Khasa and Hambling, personal communication).

Notes: Woody species were grown hydroponically in the greenhouse to determine their salt tolerance (Khasa and Hambling, personal communication). All treatments were made with 0.5% Hoagland's solution and the addition of salt or water (Khasa and Hambling, personal communication).

There were 12 jack pine seedlings in each treatment (Khasa and Hambling, personal communication). Exposure to the treatment commenced when the seedlings were 1 to 2 months old and lasted 1 month (Khasa and Hambling, personal communication). The seedlings were observed for chlorosis and survival after 1 month of exposure.

In the control, 2 jack pine seedlings developed light chlorosis, while the remainder did not exhibit any chlorosis (Khasa and Hambling, personal communication). In Treatment A, at 3.13 dS/m, 1 jack pine died, 3 had light chlorosis and the remainder did not have chlorosis (Khasa and Hambling, personal communication). In Treatment B (6.33 dS/m), 2 seedlings had moderate chlorosis, 6 had light and 4 had no chlorosis (Khasa and Hambling, personal communication). In the highest saline treatment, Treatment C (8.80 dS/m), all seedlings were observed to have chlorosis: 4 seedlings died, 2 had severe chlorosis, 4 had moderate chlorosis and 2 had light chlorosis (Khasa and Hambling, personal communication). In the CT water treatment (4.10 dS/m), 5 seedlings had light chlorosis and the remainder had no observable chlorotic effects (Khasa and Hambling, personal communication).

Literature Review - Salinity Tolerance

EC: > 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for "low", 1,500 to 3,000 ppm for "moderate" and > 3000 ppm for "high" (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report's author.

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 3.5 (Hardy BBT 1989)

Notes: Hardy BBT (1989) indicates jack pine makes reasonably good growth on soils with a pH of 4.5 to 6.5 (Fowells 1965), but a recent study has reported that jack pine has a high acid tolerance and success on very acid soil (pH 3.5). Jack pine does not grow naturally where the surface soil is alkaline, however it will grow satisfactorily on calcareous soils (pH 8.2) if normal mycorrhizal association is present (Fowells 1965).

Pinus contorta **Lodgepole pine**

EC Tolerance Range: 1.03 to 6.550 dS/m (Renault et al. 1998a)

SAR Tolerance Range: not available

pH Tolerance Range: 5.12 to 7.42 (Renault et al. 1998a)

Confidence Limit: data are inconclusive

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A; 6.97 Treatment B; 7.4 Treatment C; 7.39 Treatment D; 7.42 Treatment E and; 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four 8 month old seedlings of lodgepole pine were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all lodgepole pine seedlings were alive. Needle necrosis was observed in the 100% CT treatment (Renault et al. 1998a). The water potentials decreased in 100% CT water with and without $NaSO_4$ (Renault et al. 1998a). Transpiration rates were lower than the control after 4 weeks for Treatments E and F (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a). In the highest salt concentrations, not in all lodgepole pine seedlings had needle necrosis or changes in water potentials, which suggests a high degree of individual resistance within the species (Renault et al. 1998a).

Populus sp. Northwest hybrid poplar

EC Tolerance Range: 0.98 to 7.91 dS/m (Renault et al. 1999)

SAR Tolerance Range: 0 to 26.3 (Renault and Zwiazek 1997)

pH Tolerance Range: 5.3 to 8.4 (Renault et al. 1997)

Confidence Limit: data are inconclusive

Field Research - Syncrude U Shaped Cell (Study 97:2)

EC: 1.7 to 2.2 dS/m at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

SAR: 8.1 to 26.3 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

pH: 7.7 to 7.9 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

Notes: Seedlings planted in CT material on the U-shaped cell at Syncrude in June 1997. All hybrid poplar seedlings were alive after 2 months (Renault and Zwiazek 1997). Hybrid poplar seedlings showed shoot growth and new adventitious root growth after 2 months (Renault and Zwiazek 1997). Leaf tip necrosis was observed on 75% of hybrid poplar seedlings (Renault and Zwiazek 1997). The water potential indicated the plants were not under stress (Renault and Zwiazek 1997). Additional factors that could affect the seedlings growing in the U-shaped cell include wind, temperature, and irradiation stresses (Renault and Zwiazek 1997).

In 1998, after one year, the hybrid poplar seedlings had a survival rate of 97.2% (Renault et al. 1998). Leaf injury was observed in July 1998, but in August 1998, one month after fertilization, new growth without visible injury was present (Renault et al. 1998).

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;
- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;
- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away.

Sixty seedlings of hybrid poplar were planted in each treatment (Renault and Zwiazek 1997). Two months after planting in both 1996 and 1997, all the hybrid poplar seedlings survived the CT and FT treatments (Renault and Zwiazek 1997). Hybrid poplar trees that had been growing on site before the FT was applied survived after 2 months of treatment (Renault and Zwiazek 1997). One year after planting, the survival rate was 100% (Renault and Zwiazek 1997). Shoot growth was significantly increased in the FT treatment during the 2 month study (Renault and Zwiazek 1997). Water potentials, transpiration and diffusive resistance of seedlings planted in 1996 and 1997 were not affected by the presence of CT and FT when measured 3 weeks and 2 months after treatment (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A, 6.97 Treatment B, 7.4 Treatment C, 7.39 Treatment D, 7.42 Treatment E and 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four cuttings of hybrid poplar were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all hybrid poplar seedlings were alive. Leaf necrosis was not observed (Renault et al. 1998a). Water potentials were not affected (Renault et al. 1998a). Transpiration rates were lower than the control after 4 weeks for Treatments C, D, E and F (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a).

Greenhouse Hydroponics Research - Syncrude CT Water

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault et al. 1999).

SAR: not available

pH: 5.3 in control Treatment A; 7.9 Treatment B; 8.0 Treatment C; 8.4 Treatment D and; 8.4 Treatment E (Renault et al. 1999).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault et al. 1999).

Twenty-four 1 year old seedlings of hybrid poplar were grown in a hydroponics system (Renault et al. 1999). After 4 weeks, 87.5% of seedlings survived in Treatment E (Renault et al. 1999). In the remaining treatments, survival of hybrid poplar seedlings after 4 weeks was 100% (Renault et al. 1999). Leaf tip necrosis and leaf chlorosis in Treatments C, D and E occurred (Renault et al. 1999). Root growth was reduced in Treatments C, D and E except for some seedlings in Treatment E (Renault et al. 1999). Water potentials were not affected after 4 weeks in any treatments (Renault et al. 1999). Transpiration rates were significantly lower than the control after 4 weeks in Treatments C, D and E (Renault et al. 1999). Leaf diffusive resistance was significantly increased from the control after 4 weeks in Treatments C and D (Renault et al. 1999).

Populus balsamifera **Balsam poplar**

EC Tolerance Range: 14.58 to 31.38 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.2 to 8.2 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.58 to 31.38 dS/m at 50 cm; 9.89 to 12.85 dS/m at 150 cm; groundwater: 14.35 to 21.57 dS/m Stage V sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: 7.4 to 8.2 at 50 cm; 7.2 to 8.0 at 150 cm; groundwater pH 7.2 to 7.8 Stage V sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 50 and 150 cm below the soil surface at Stage V (Yarie et al. 1993).

Greenhouse Hydroponics Research - Suncor CT Water (Study 97:8)

EC: 1.047 dS/m in control (Treatment A) (deionized water only); 1.455 dS/m with 25% CT water (Treatment B); 1.958 dS/m with 50% CT water (Treatment C); 2.958 dS/m with 100% CT water (Treatment D) and 4.44 dS/m with 100% CT water and 1420 ppm $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997).

SAR: not available

pH: not available

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatment E) (Renault and Zwiazek 1997). Twenty-four seedlings of balsam poplar were grown in a hydroponics system (Renault and Zwiazek 1997). After 4 weeks, no seedlings survived the 100% CT water plus $NaSO_4$ treatment (Renault and Zwiazek 1997). In 2 treatments, 50% of balsam poplar seedlings survived (25% CT water and 100% CT water treatments), but 67% survived the 50% CT water treatment (Renault and Zwiazek 1997). All seedlings survived in the control (Renault and Zwiazek 1997). Leaf necrosis and a reduction of root growth were detected in balsam poplar in the 25% CT water (Renault and Zwiazek 1997). Water potentials and transpiration rates were reduced in all CT water treatments (Renault and Zwiazek 1997).

Populus tremuloides Trembling aspen

EC Tolerance Range: 0.98 to 7.91 dS/m (Renault et al. 1999)

SAR Tolerance Range: 0 to 26.3 (Renault and Zwiazek 1997)

pH Tolerance Range: 3.2 to 4.5 (Balsillie et al. 1978); 5.3 to 8.4 (Renault et al. 1999)

Confidence Limit: data are suggestive

Field Research - Capping Material

EC: 1.2 to 2.2 dS/m, $CaSO_4$ predominantly (HBT AGRA 1994).

SAR: 1.2 to 1.7 (Fair soils); 3.4 (Poor soils) $NaSO_4$ (HBT AGRA 1994).

pH: 7.4 to 7.5 (HBT AGRA 1994).

Notes: In 1990**,** HBT AGRA commenced research on aspen, jack pine, white spruce and dogwood growing on capped overburden at Syncrude (HBT AGRA 1994). Each of the four fertilized plots received seedlings of the same species, but the quality and depth of the capping material was different for each plot. Three plots have 'fair' quality capping material of 30, 50 and 70 cm thickness and 1 plot has 'poor' quality capping material of 70 cm thickness (HBT AGRA 1994). Soil suitability ratings were based on criteria from the Soil Quality Working Group (1987) for reclamation in Alberta (HBT AGRA 1994). The 'poor' soil had a heavier texture (HBT AGRA 1994) and a higher SAR compared to the 'fair' soils (Warner personal communication).

Three growing seasons after transplanting (1993), aspen seedlings had an 80% survival (Warner, personal communication). The differences among treatments were not statistically significant (HBT AGRA 1994). The vegetation was measured again in 1996. All species appeared healthy and there was no statistical difference in tree growth between the 4 treatment plots (Warner, personal communication). The differences among the plots may become apparent when the trees become mature and their roots extend into the overburden (Warner, personal communication).

Field Research - Syncrude U Shaped Cell (Study 97:2)

EC: 1.7 to 2.2 dS/m at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

SAR: 8.1 to 26.3 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

pH: 7.7 to 7.9 at 30 cm depth in CT material at Syncrude U shaped cell Study 97:2 (Renault and Zwiazek 1997).

Notes: Seedlings planted in CT material on the U-shaped cell at Syncrude in June 1997. Aspen seedlings were all alive after 2 months (Renault and Zwiazek 1997). Leaf tip necrosis was observed on 100% of hybrid poplar seedlings (Renault and Zwiazek 1997). The water potential indicated the aspen seedlings were under stress (Renault and Zwiazek 1997). Additional factors that could affect the seedlings growing in the U-shaped cell include wind, temperature, and irradiation stresses (Renault and Zwiazek 1997). In 1998, after one year, the aspen seedlings had a survival rate of 94.4% (Renault et al. 1998). Leaf injury was observed in July 1998 (Renault et al. 1998).

Field Research - Vegetation and Soils Inventory in an Undisturbed Site

EC: 0.3 dS/m Ae, 0 to 12 cm; EC 2.8 dS/m, Bnt1 12 to 37 cm; EC 3.2 dS/m, Bnt2, 37 to 60 cm (Alberta Environment 1982).

SAR: 1.86 Ae, 0 to 12 cm; SAR 1.69, Bnt1, 12 to 37 cm; SAR 1.77, Bnt2, 37 to 60 cm (Alberta Environment 1982).

pH: 4.3, Ae, 0 to 12 cm; pH 6.0, Bnt1, 12 to 37 cm; pH 6.8, Bnt2, 37 to 60 cm (Alberta Environment 1982).

Notes: Soil survey of an undisturbed area west of Fort McMurray, Alberta, NW17-97-12-W4. Soil is a Gray Solodized Solonetz (Joslyn series). Larry Turchenek (personal communication), conducted the soil survey and recalled the vegetation in this area was short and stunted. Area was imperfectly drained, so the hydrology of the area may have also influenced vegetation health (Turchenek personal communication). Alder was associated with aspen and bunchberry (Alberta Environment 1982).

Field Research - Syncrude CT and FT (Study 5)

EC: 0.73 to 0.84 dS/m in control; 0.71 to 1.07 dS/m in consolidated tailings (CT) treatment and; 0.74 to 1.64 dS/m in fine tailings (FT) Study 5 (Renault and Zwiazek 1997).

SAR: 1.2 to 1.7 in control; 1.8 to 2.4 in consolidated tailings (CT) treatment and; 2.3 to 7.2 in fine tailings (FT) treatment Study 5 (Renault and Zwiazek 1997).

pH: 7.3 to 7.6 in control; 7.5 to 7.6 in consolidated tailings (CT) treatment and; 7.5 to 7.7 in fine tailings (FT) treatment Study 5 (Renault and Zwiazek 1997).

Notes: There were three treatments for this research:

- Control: 70 cm of reclamation material on top of tailings sands;

- CT treatment: CT spread on top of 70 cm of reclamation material to produce a ratio of 30 L CT m^2 and then mixed into the top 20 cm of reclamation material and;

- FT treatment: FT spread on top of 70 cm of reclamation material to produce a ratio of 15 L FT m^2 and then mixed into the top 20 cm of reclamation material (Renault and Zwiazek 1997).

This experiment was conducted in June 1996 and repeated in June 1997 the experiment was repeated at a site about 50 m away. Sixty aspen seedlings were planted in June 1996 and in June 1997 (Renault and Zwiazek 1997). One year after planting, the survival rate was 100% (Renault and Zwiazek 1997). Aspen seedlings after 3 weeks in the FT treatment had lower water potentials than control plants (Renault and Zwiazek 1997). In the CT treatment in 1996, aspen seedlings had decreased transpiration rates, indicating stress (Renault and Zwiazek 1997). But in 1997, there was no observable effect of FT or CT on aspen seedlings and the transpiration rates in the FT treatment exceeded control (Renault and Zwiazek 1997).

Greenhouse Hydroponics Research - Syncrude CT Water

EC: 0.979 dS/m in control (Treatment A) (deionized water only); 2.090 dS/m with 25% CT water (Treatment B); 3.290 dS/m with 50% CT water (Treatment C); 5.400 dS/m with 100% CT water (Treatment D) and 7.910 dS/m with 100% CT water plus 1420 ppm $NaSO_4$ and 585 ppm NaCl (Treatment E) (Renault et al. 1999).

SAR: not available

pH: 5.3 in control Treatment A; 7.9 Treatment B; 8.0 Treatment C; 8.4 Treatment D and; 8.4 Treatment E (Renault et al. 1999).

Notes: Half strength Hoagland's solution was used in each treatment except for the control and combined with various proportions of Syncrude's CT water and in CT water and $NaSO_4$ plus NaCl (Treatment E) (Renault et al. 1999).

Twenty-four aspen seedlings (1 year old) were grown in a hydroponics system (Renault et al. 1999). After 4 weeks, 87.5% of seedlings survived in Treatment E (Renault et al. 1999). In the remaining treatments, survival of aspen seedlings after 4 weeks was 100% (Renault et al. 1999). Leaf necrosis followed by leaf abscission in Treatment D (Renault et al. 1999). After the loss of leaves, the seedlings rapidly recovered and produced new leaves (Renault et al. 1999). Water potentials were decreased after 4 weeks in Treatments C, D and E (Renault et al. 1999). Transpiration rates were significantly lower than the control after 4 weeks in Treatments D and E (Renault et al. 1999). Leaf diffusive resistance was significantly greater than the control after 4 weeks in Treatments D and E (Renault et al. 1999).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A, 6.97 Treatment B, 7.4 Treatment C, 7.39 Treatment D, 7.42 Treatment E and 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four cuttings of aspen were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all aspen seedlings were alive. Leaf necrosis was followed by leaf abscission which occurred after 2 weeks of treatment with 100% CT water (Renault et al. 1998a). One week later, new leaves were produced indicating that the loss of leaves may be due to a stress response or an accumulation of toxic levels of ions in the leaves (Renault et al. 1998a). Water potentials were affected in Treatments D, E and F (Renault et al. 1998a). Transpiration rates were lower than the control after 4 weeks for Treatments E and F (Renault et al. 1998a). Membrane leakage was not significant in any treatment (Renault et al. 1998a).

Greenhouse Hydroponics Research - Saline Water

EC: 1.016 dS/m in control; 25mM NaCl, 3.13 dS/m (Treatment A); 50 mM NaCl, 6.33 dS/m (Treatment B); 75 mM NaCl, 8.80 dS/m (Treatment C) and; CT water from Syncrude, 4.10 dS/m (Treatment D) (Khasa and Hambling, personal communication).

SAR: not available

pH: 6.96 Control; 6.93 Treatment A; 6.94 Treatment B; 6.94 Treatment C; 8.06 Treatment D (Khasa and Hambling, personal communication).

Notes: Woody species were grown hydroponically in the greenhouse to determine their salt tolerance (Khasa and Hambling, personal communication). All treatments were made with 0.5% Hoagland's solution and the addition of salt or water (Khasa and Hambling, personal communication). There were 48 aspen seedlings in each treatment (Khasa and Hambling, personal communication). Exposure to the treatment commenced when the seedlings were 1 to 2 months old and lasted 1 month (Khasa and Hambling, personal communication). The seedlings were observed for chlorosis and survival after 1 month of exposure.

In the control, 4 aspen seedlings died, 16 had severe chlorosis, 15 had moderate chlorosis, 10 had light chlorosis and 3 did not exhibit any chlorosis (Khasa and

Hambling, personal communication). In the remaining treatments, all seedlings died. (Khasa and Hambling, personal communication).

Literature Review - Salinity Tolerance

EC: 2 to 4 dS/m (Edwards 1985)

SAR: not available

pH: not available

Notes: Edwards (1985) indicates plant tolerance to salinity is difficult to categorize because test results have been taken from different sources and obtained under widely different conditions. However, if critical levels are those at which toxicity symptoms appear, including growth suppression, then some limits can be established based on arbitrary concentrations: < 1500 ppm for “low”, 1,500 to 3,000 ppm for “moderate” and > 3000 ppm for “high” (Edwards 1985). These categories are roughly equivalent to < 2 dS/m (low), 2 to 4 dS/m (moderate) and > 4 dS/m (high). Salinity levels of < 2 dS/m have suppressed the growth of conifer seedlings in nurseries (Edwards 1985). Deciduous species are reported to be more tolerant of soil salinity (Edwards 1985). Please note Edwards (1995) used only the common name for this species, the Latin name has been added by the report’s author.

Literature Review - Salinity Tolerance

EC: not available

SAR: not available

pH: 3.2 to 4.5 (Balsillie et al. 1978)

Notes: Hardy BBT (1989) indicates aspen had poor survival on sodic mine spoils at Wabamum, AB. (Montreal Engineering Company 1979). It has been reported to have low acid tolerance (Alaska Rural Development Council 1977). However, it has been observed as a successional species on flat barren sand areas near Sudbury, ON. The soils there are very acidic (pH 3.2 to 4.5) (Balsillie et al. 1978).

Salix amygdaloides **Peachleaf willow**

EC Tolerance Range: 1.03 to 6.550 dS/m (Renault et al. 1998a)

SAR Tolerance Range: 8.1 to 26.3 (Renault and Zwiazek 1997)

pH Tolerance Range: 5.12 to 7.9 (Renault et al. 1998a) and (Renault and Zwiazek 1997)

Confidence Limit: data are inconclusive

Field Research - Syncrude U Shaped Cell (Study 97:2)

EC: 1.7 to 2.2 dS/m at 30 cm depth in CT material at Syncrude U shaped cell (Renault and Zwiazek 1997).

SAR: 8.1 to 26.3 at 30 cm depth in CT material at Syncrude U shaped cell (Renault and Zwiazek 1997).

pH: 7.7 to 7.9 at 30 cm depth in CT material at Syncrude U shaped cell (Renault and Zwiazek 1997).

Notes: Seedlings planted in CT material on the U-shaped cell at Syncrude in June 1997. All peachleaf willow seedlings were alive after 2 months (Renault and Zwiazek 1997). Peachleaf willow seedlings showed new root and shoot growth after 2 months (Renault and Zwiazek 1997). Leaf tip necrosis was observed on 100% of hybrid poplar seedlings (Renault and Zwiazek 1997). The water potential indicated the plants were not under stress (Renault and Zwiazek 1997). In July, willow showed a high diffusive resistance and low transpiration rates suggesting a partial closure of the stomata (Renault and Zwiazek 1997). However, in August, this trend reversed (Renault and Zwiazek 1997). Additional factors that could affect the seedlings growing in the U-shaped cell include wind, temperature, and irradiation stresses (Renault and Zwiazek 1997).

In 1998, after one year, the peachleaf willow seedlings had a survival rate of 94.4% (Renault et al. 1998). Leaf injury was observed in July 1998, but after fertilization in August 1998 willow showed new growth without visible injury (Renault et al. 1998).

Greenhouse Hydroponics Research - Suncor CT Water

EC: 1.029 dS/m in control (Treatment A) (half strength Hoagland's solution in deionized water); 1.502 dS/m with 25% CT water (Treatment B); 2.030 dS/m with 50% CT water (Treatment C); 3.000 dS/m with 100% CT water (Treatment D); 4.210 dS/m with 100% CT water plus 1 g/L $NaSO_4$ and; 6.550 dS/m with 100% CT water plus 3 g/L $NaSO_4$ (Treatment E) (Renault et al. 1998a).

SAR: not available

pH: 5.12 in control Treatment A; 6.97 Treatment B; 7.4 Treatment C; 7.39 Treatment D; 7.42 Treatment E and; 7.09 Treatment F (Renault et al. 1998a).

Notes: Half strength Hoagland's solution was used in each treatment and combined with various proportions of Suncor's CT water and in CT water and $NaSO_4$ (Treatments E and F) (Renault et al. 1998a).

Twenty-four cuttings of willow were grown in a hydroponics system (Renault et al. 1998a). After 4 weeks, all willow seedlings were alive. Leaf necrosis was followed by leaf abscission which occurred after 2 weeks of treatment with 100% CT water (Renault et al. 1998a). One week later, new leaves were produced indicating that the loss of leaves may be due to a stress response or an accumulation of toxic levels of ions in the leaves (Renault et al. 1998a). Water potentials were significantly different from the control after 4 weeks in Treatments D, E and F (Renault et al. 1998a). Transpiration rates were significantly lower than the control after 4 weeks for Treatments D, E and F (Renault et al. 1998a). Membrane leakage was observed in Treatments E and F (Renault et al. 1998a).

Salix interior **Narrow-leaved willow**

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

Salix lasiandra **Pacific willow**

EC Tolerance Range: 14.39 to 31.24 dS/m (Yarie et al. 1993)

SAR Tolerance Range: not available

pH Tolerance Range: 7.0 to 7.9 (Yarie et al. 1993)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: soil-solution: 14.39 to 31.24 dS/m at 20 cm; 12.09 to 29.56 dS/m at 50 cm; groundwater 9.10 to 18.21 dS/m Stage III sites. Ions with the highest concentrations were Na, Cl and HCO_3 (Yarie et al. 1993).

SAR: not available

pH: soil-solution: 7.3 to 7.9 at 20 cm; 7.0 to 7.7 at 50 cm; groundwater pH 7.2 to 7.7 Stage III sites (Yarie et al. 1993).

Notes: The vegetation and soils of the Tanana River floodplain were studied to document soil-solution chemical concentrations for representative stages of primary succession (Yarie et al. 1993). The Tanana River is located in interior Alaska. Twelve stages of succession have been recognized and three are correlated to soil and groundwater pH and EC: Stage III open willow; Stage V balsam poplar and thinleaf alder and; Stage VIII white spruce (Yarie et al. 1993). The EC values are average yearly values collected from 1986 to 1988 and the pH values are from 1985 to 1988 (Yarie et al. 1993). Conductivity decreased with depth (Yarie et al. 1993). Samplers were placed at 20 and 50 cm below the soil surface at Stage III sites due to the shallow water table (Yarie et al. 1993).

10.0 RIPARIAN SPECIES

10.1 Grasses

Scirpus maritimus **Prairie bulrush**

EC Tolerance Range: 8.2 dS/m at Site 9 (Lieffers 1984)

SAR Tolerance Range: not available

pH Tolerance Range: 9.7 at Site 9 (Lieffers 1984)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed area

EC: water specific conductance 8.2 dS/m at Site 9 (Lieffers 1984)

SAR: not available

pH: 9.7 at Site 9 (Lieffers 1984)

Notes: Fifteen oxbow lakes with varying degrees of salinity were used in a research initiative to identify the vegetation in the emergent zones (Lieffers 1984). The oxbow lakes were located along the Athabasca River between 10 and 60 km north of Fort McMurray (Lieffers 1984). There were 16 sites in the emergent zones from the forest fringe to open water, but only one site was very saline with stable water levels (Site 9) (Lieffers 1984). Prairie bulrush was observed in near open water (Lieffers 1984).

Scolochloa festucacea **Spangletop**

EC Tolerance Range: 8.2 dS/m at Site 9 (Lieffers 1984)

SAR Tolerance Range: not available

pH Tolerance Range: 9.7 at Site 9 (Lieffers 1984)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed area

EC: water specific conductance 8.2 dS/m at Site 9 (Lieffers 1984)

SAR: not available

pH: 9.7 at Site 9 (Lieffers 1984)

Notes: Fifteen oxbow lakes with varying degrees of salinity were used in a research initiative to identify the vegetation in the emergent zones (Lieffers 1984). The oxbow lakes were located along the Athabasca River between 10 and 60 km north of Fort McMurray (Lieffers 1984). There were 16 sites in the emergent zones from the forest fringe to open water, but only one site was very saline with stable water levels (Site 9) (Lieffers 1984). Spangletop was observed in narrow bands near the forest fringe along with awned sedge (Lieffers 1984).

Triglochin maritima Seaside arrow-grass

EC Tolerance Range: 13.6 to 32.7 dS/m (Burchill and Kenkel 1991)

SAR Tolerance Range: not available

pH Tolerance Range: 9.7 at Site 9 (Lieffers 1984)

Confidence Limit: data are suggestive

Field Research - Vegetation and Soil Inventory in an Undisturbed area

EC: water specific conductance 8.2 dS/m at Site 9 (Lieffers 1984)

SAR: not available

pH: 9.7 at Site 9 (Lieffers 1984)

Notes: Fifteen oxbow lakes with varying degrees of salinity were used in a research initiative to identify the vegetation in the emergent zones (Lieffers 1984). The oxbow lakes were located along the Athabasca River between 10 and 60 km north of Fort McMurray (Lieffers 1984). There were 16 sites in the emergent zones from the forest fringe to open water, but only one site was very saline with stable water levels (Site 9) (Lieffers 1984). Sea arrow-grass was observed in a 60 m wide band in the emergent zone with 84% cover (Lieffers 1984).

Field Research - Vegetation and Soil Inventory in an Undisturbed Area

EC: mean: 23.1 dS/m; range from 13.6 to 32.7 dS/m (Burchill and Kenkel 1991)

SAR: not available

pH: mean 8.1, range 7.6 to 8.6 (Burchill and Kenkel 1991)

Notes: This research was conducted on an inland salt pan in an undisturbed area near the northwestern shore of Lake Winnipegosis, Manitoba (Burchill and Kenkel 1991). Soil and vegetation sampling were conducted at 3 sites: 2 salt flats and 1 saline meadow. The vegetation was divided into eight plant associations, based on the dominant plant species in the group and the tolerance range for soil salinity (Burchill and Kenkel 1991). The order of the associations from highest to lowest salinity is: Salt Pan, Puccinellia, Triglochin, Hordeum, Spartina, Agropyron, Calamagrostis and Rosa (Burchill and Kenkel 1991). The Salt Pan association has very low plant cover and salt tolerant annuals with no single dominant species (Burchill and Kenkel 1991). Seaside arrow-grass and alkali grass have the highest mean cover in the Salt Pan association (Burchill and Kenkel 1991).

10.2 Sedges

Carex atherodes Awned sedge

EC Tolerance Range: 8.2 dS/m at Site 9 (Lieffers 1984)

SAR Tolerance Range: not available

pH Tolerance Range: 9.7 at Site 9 (Lieffers 1984)

Confidence Limit: data are inconclusive

Field Research - Vegetation and Soil Inventory in an Undisturbed area

EC: water specific conductance 8.2 dS/m at Site 9 (Lieffers 1984)

SAR: not available

pH: 9.7 at Site 9 (Lieffers 1984)

Notes: Fifteen oxbow lakes with varying degrees of salinity were used in a research initiative to identify the vegetation in the emergent zones (Lieffers 1984). The oxbow lakes were located along the Athabasca River between 10 and 60 km north of Fort McMurray (Lieffers 1984). There were 16 sites in the emergent zones from the forest fringe to open water, but only one site was very saline with stable water levels (Site 9) (Lieffers 1984). Awned sedge was observed in narrow bands near the forest fringe along with spangletop (Lieffers 1984).