REPORT #
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Salt Movement in Disturbed Soils

by

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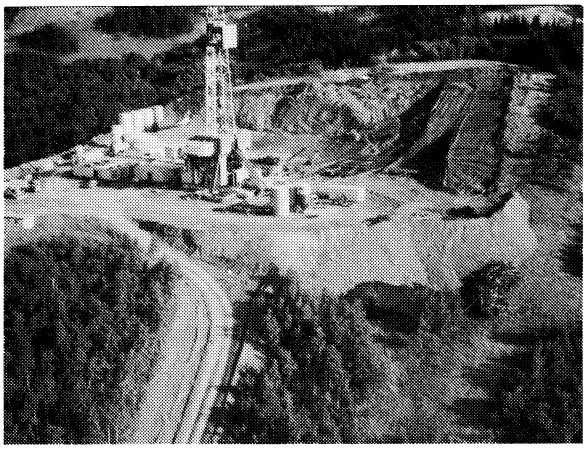
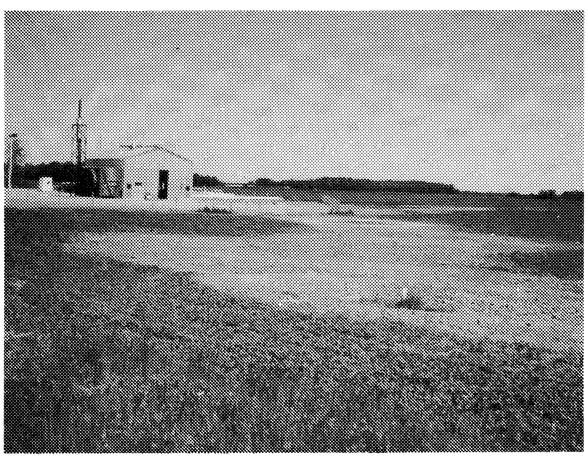
ALBERTA CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

1993

Oil and Gas Reclamation Research Program





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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Conservation and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

REVIEWS

This report was reviewed by RRTAC and the Soil Handling Subcommittee of the Alberta Pipeline Environmental Steering Committee.

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ABSTRACT

This literature review compiles information on salt movement in disturbed soils, particularly in soils that had been disturbed by pipeline construction. The review had two main objectives: to assess climatic and soil conditions under which salts will move out of the root zone in a disturbed soil and to determine the rate at which salts will move in disturbed soils. A literature base was established using computer database and library searches, and a number of studies were reviewed. Many of them, dealing specifically with salt movement over time in disturbed soils under climate and soil conditions similar to those found in Alberta, are summarized in tabular form.

Data found in the literature tended to be sparse and incomplete, making it difficult to draw firm conclusions about rates of salt movement and conditions under which movement takes place. In the Brown Soil Zone, 5 years may be sufficient time for sodium adsorption ratio (SAR) and electrical conductivity (EC) levels, elevated during construction, to return to pre-construction conditions in coarse to moderately coarse textured soils. In medium to moderately fine textured soils, 10 to 26 years may be required to return soil salt content to pre-construction conditions. In the Dark Brown Soil Zone, 5 years appears to be marginal for a return to pre-construction conditions, being sufficient time in some cases, but not in others. Data in the Black Soil Zone were very limited, and results inconsistent. Studies from the U.S. were generally the result of research on mine reclamation. Most reported decreases in salts over relatively short periods of time, but the magnitude of the decrease varied greatly from study to study.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Reclamation Research Technical Advisory Committee (RRTAC) of the Alberta Conservation and Reclamation Council who managed the project. The project was initiated by the Soil Handling Subcommittee of APESC. Funding for the project was provided through the Alberta Heritage Savings Trust Fund, Land Reclamation Program, Canadian Association of Petroleum Producers (CAPP), and NOVA Corporation of Alberta.

A number of people assisted in the production of this report. Margaret Harris carried out the computer database search. Rhonda Penny and Karen Cannon assisted in the manual library search, and the review and summary of papers. Margaret Harris also edited the final document.

Special thanks are due a number of people who reviewed the report, especially Don Thacker, Wayne Tedder, Chris Powter, Al Fedkenheuer, Jim Burke, and Travis Ferguson.

1. INTRODUCTION

In response to concerns about loss of soil quality during pipeline construction through saline and sodic soils and parent materials, the Alberta Pipeline Environmental Steering Committee (APESC) released interim guidelines on soil handling procedures for pipeline construction through salt-affected soils (Alberta Pipeline Environmental Steering Committee 1992). This document outlines a set of criteria for determining whether special 3-lift soil handling (in which upper root zone or B horizon material is salvaged separately from topsoil and lower subsoil material) will be required to preserve soil quality for any given soil.

One of the issues discussed in the above document is the period of time required for salts introduced into the topsoil and upper subsoil root zone during pipeline construction to leach or move out of the root zone naturally. If the salt content of the reconstructed root zone decreases naturally to within what can be considered an acceptable range within 2 to 5 years, it may be assumed that 3-lift construction need not occur. Hence soil and climatic conditions required for salt movement out of the upper soil profile in disturbed soils in Alberta, and the rates of salt movement under different conditions, need to be assessed.

At present, the APESC criteria vary for different soil zones in the province. Whether or not these criteria adequately take into consideration differences in mobility and persistence of salts introduced into the root zone for different areas also needs to be assessed.

The objective of this study was to undertake a review of information on salt movement in disturbed soils, particularly with reference to pipelines. This review assesses the climate and soil conditions under which salts will move out of the root-zone, and the rates at which salts will move in disturbed soils. This review does not assess the relative effectiveness of 3-lift soil handling procedures compared to conventional 2-lift soil handling procedures; nor does it deal with salt re-distribution during pipeline construction and reclamation.

1.1 MECHANISMS OF SALT MOVEMENT

Soluble salts by their nature are highly mobile in soils. In central and eastern Alberta, sodium sulphate is the dominant soluble salt (VanderPluym and Harron 1992). Bicarbonate and chloride salts are found in smaller amounts. Solubilities of salts common in central and southern Alberta soils are presented in Table 1.

Soluble salts can move in any direction by leaching through the soil, by capillary action (Alberta Agriculture, n.d.; Brady 1990; Landsburg 1981), or by chemical diffusion (Merrill et al. 1980). Leaching is the predominant mechanism that causes salts to move vertically down through the soil profile, although sometimes the movement is lateral as well as vertical. The amount and rate of downward leaching of soluble salts depends on a number of factors, including:

1. Amount of water available to leach through the soil profile, which is a function of precipitation and evapo-transpiration; and
2. Hydraulic conductivity of the soil, which is mainly a function of soil texture (chiefly clay content) and saturating cations (chiefly sodium).

Table 1. Common salts in Alberta and their solubility in pure water at 20°C.[1]

Salt	Chemical Formula	Solubility (g/L)
Sodium sulphate	$Na_2SO_4.10H_2O$	160
Calcium sulphate (gypsum)	$CaSO_4.2H_20$	2
Sodium chloride	NaCl	264
Calcium chloride	$CaCl_2$	427
Calcium carbonate	$CaCO_3$	0.01

[1] Source: VanderPluym and Harron (1992).

Capillary action can move salts with pore water upward into the root zone of the soil profile from a high water table. Factors affecting the salinization of root zone material by capillary action include:

1. Amount of capillary rise in the soil, which is dependent on soil hydraulic conductivity; and
2. Depth to water table, since capillary rise is normally less than 1 m.

Movement of soluble salts by chemical diffusion has been documented in a number of studies, most notably those in which non-saline, non-sodic soil has been replaced over strongly saline spoil materials in a strip mine operation (Merrill et al. 1980). Movement of salt by chemical diffusion generally occurs within 30 cm above the soil/saline spoil interface. Factors affecting salinization by chemical diffusion include:

1. Sharpness of gradient between non-saline soil materials and underlying strongly saline spoil materials; and
2. Hydraulic conductivity of the materials, those with low hydraulic conductivity being most susceptible.

Salt movement can also occur when saline soil pore water moves through the soil in response to a temperature gradient. This mechanism results in upward movement of salt during the winter, as soil water tends to move from the warmer areas at lower depths, to the cooler freezing front near the surface of the soil (Cary and Mayland 1972; Landsburg 1981).

These mechanisms of salt movement can result in seasonal fluctuations in soil salinity. These fluctuations could affect the soil sampling methodology used to assess the need for 3-lift soil handling during pipeline construction. There are a number of studies on both irrigated and drained soils and non-irrigated soils, in Alberta and elsewhere, which indicate considerable within-year variation of soil salinity levels (Buckland and Hendry 1992; Graveland 1970; Landsburg 1981; Miller and Read 1992). For example, Landsburg (1981) found that soil EC varied by more than 2 dS/m at various depths during the year, with measurements taken weekly during the frost-free period. No similar work on disturbed soils is known.

1.2 EFFECT OF SOIL SALINITY AND SODICITY ON PLANTS

Salts in soils affect plants by preventing the normal uptake of soil water and dissolved nutrients into the plant. Tolerance to soil salts varies for different plants. Sommerfeldt and Rapp (1982) indicate, for example, that field beans and corn have a low tolerance to salts; canola, wheat, and oats have a moderate tolerance; and barley and sugar beets tend to have a high tolerance to salts. Soil sodicity causes adverse soil physical properties. Sodic or Solonetzic soils tend to be very hard when dry, and sticky, massive, and impermeable when wet. Plant root penetration is restricted, and plants are particularly susceptible to drought. Some effects of soil salinity levels on plant growth are shown in Table 2. EC and SAR soil quality criteria for rating the suitability of soils for reclamation are presented in Table 3.

Forage and grain crop yields are affected by many other factors besides soil salinity and sodicity. In the experience of the author, the amount and timing of precipitation tends to be the main limiting factor to plant growth in the Plains Region of Alberta. Soil fertility status, soil physical properties, soil management, and other parameters are also important. Consequently it is often difficult to separate vegetation effects due to changes in soil sodicity and salinity from effects due to other parameters. Deep plowing, for example, can increase topsoil salinity and sodicity to some degree while increasing crop yields. In these cases, the net benefit of improved soil physical structure out-weighs the disadvantages of increased salinity or sodicity. It is also difficult to compare crop yields from year to year as EC and SAR change because of the large number of other parameters affecting crop yield which also change.

1.3 SOIL DISTURBANCES

Soils can be disturbed in a number of ways, all of which can redistribute soil salts within the soil profile and reduce soil quality for agriculture or forestry. Data from strip mining, pipelining, deep plowing, and ripping (subsoiling) studies have been used in this review.

Table 2. Effects of soil salinity levels on plant growth.[1]

Salinity[2] (dS/m)	Common Features
2	- no apparent signs - affects sensitive crops
4	- presence of foxtail - some white specks on soil surface - crop growth affected to some extent
8	- plants restricted to salt tolerant species (eg. Kochia) - white salt crusts common - crops strongly affected
16	- plants restricted to species such as red samphire. - salt crust and salts throughout soil profile - little or no crop growth

[1] Source: Pettapiece (1987)
[2] Measured in saturated paste

Table 3. Suitability of topsoil and subsoil materials for reclamation in the Plains Region of Alberta[1].

	Parameter	Rating			
		Good	Fair	Poor	Unsuitable
Topsoil	EC (dS/m)	<2	2 to 4	4 to 8	>8
	SAR	<4	4 to 8	8 to 12	>12[2]
Subsoil	EC (dS/m)	<3	3 to 5	5 to 10	>10
	SAR	<4	4 to 8	8 to 12	>12

[1] Information from Alberta Agriculture (1987).
[2] 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.

Pipeline construction generally results in a narrow, linear disturbance. Depending on the diameter of the pipeline, depth of topsoil, the materials to be transported, and site specific conditions such as foreign line and road crossings, pipeline trenches can be 1 to 3 m or more in depth and up to 3 m wide. In addition, soils on spoil storage areas and work areas may also be disturbed. Normal pipeline construction procedures through cultivated or potentially cultivated land require that topsoil be stripped and windrowed separately from trench spoil material. During reclamation, topsoil is replaced over spoil in the trench. Salts can be introduced into the root zone during pipeline construction in a number of ways, including:

1. Mixing of saline lower subsoil with better quality upper subsoil during trenching;
2. Poor topsoil stripping or replacement operations; and
3. Tillage of soil through thin topsoil into underlying saline spoil material.

Note that on some of the older pipelines studied, topsoil was not stripped before construction. In areas of saline subsoils, this practice probably resulted in an initial increase in salts in surface soils of the reconstructed trench.

Strip mines result in much larger, more site specific disturbances than pipelines, both in areal extent and in depth. Most strip mining operations salvage and store topsoil, good quality subsoil, and spoil. The spoil consists of all overburden material below subsoil to the minerals being mined. Spoil is often of very poor quality for reclamation. When strip mined areas are reclaimed, layers of topsoil and subsoil are replaced over the spoil. Salts can be introduced into the root zone if salvage and storage operations are not correctly done, or if there is little good quality material available for reclamation.

Deep plowing and deep ripping (also known as subsoiling) are used to ameliorate Solonetzic soils for agriculture. The deep plow is designed to physically mix Bnt and Cca horizons, breaking up the hardpan associated with the Bnt and allowing calcium from the C horizon to mix with the Bnt. In an exchange reaction, calcium replaces sodium on the soil cation exchange complex, thus improving soil structure and inhibiting the reformation of the hardpan. Deep ripping simply breaks up the hardpan of the Solonetzic Bnt without actively inverting soil horizons, although a certain amount of soil mixing will occur.

2. METHODS

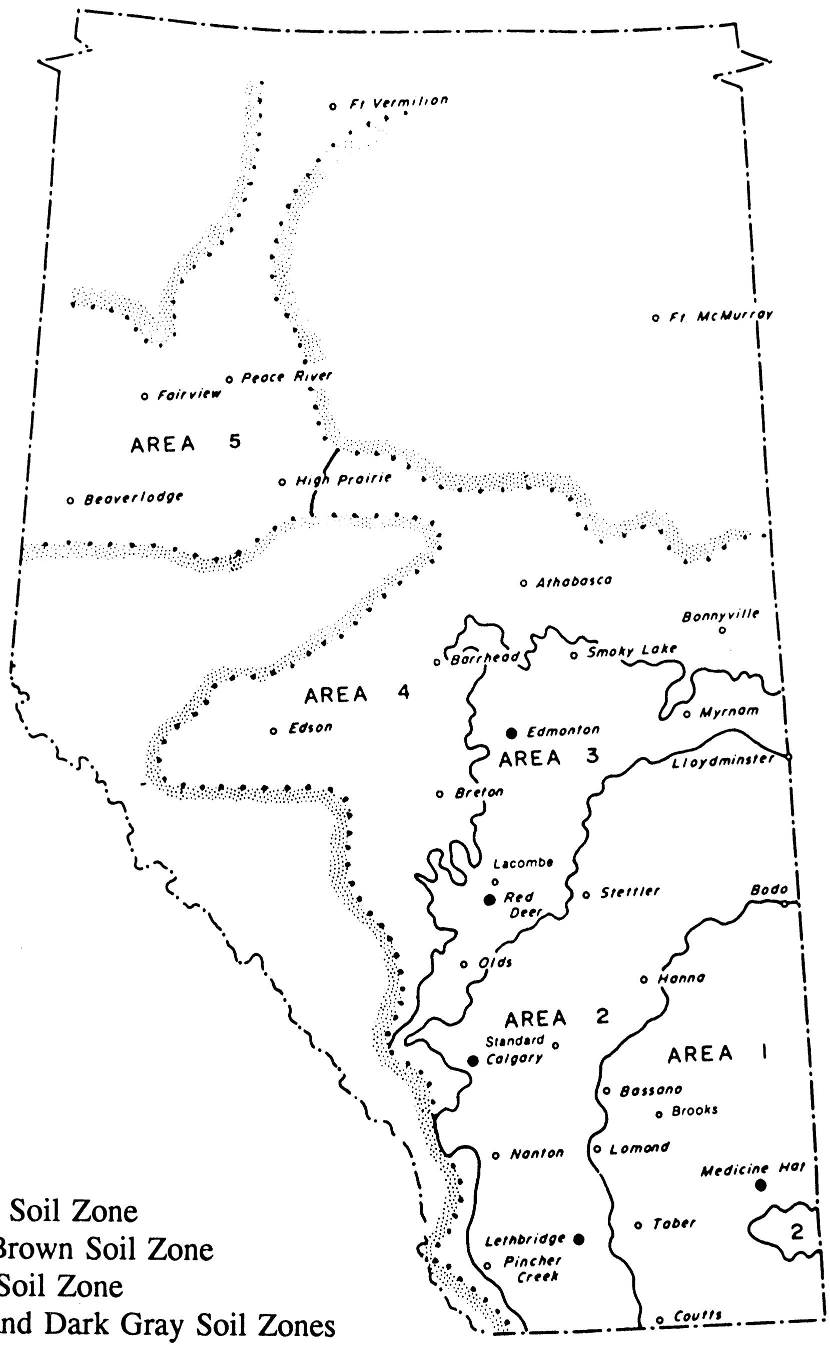
Citations to relevant literature were obtained through computer searches of the RECLAIM database, the AGRICOLA database, and the Commonwealth Agricultural Bureaux (CAB) database. Additional references were obtained from literature cited in articles selected through the computer search, from manual library searches, and from researchers working in the field.

In order to be included in this literature review, papers had to meet the following criteria:

1. Study must deal specifically with disturbed soils--mining, pipelining, or deep plowing.
2. Study must present data on the movement of salts over a period of time.
3. Paper may be refereed or non-refereed, but must present unambiguous data.
4. Study must present data from actual field research; laboratory, greenhouse, column, lysimeter, modeled, or theoretical studies or results excluded.
5. Study must include data from the Brown, Dark Brown, and Black soils zones (Figure 1) and their U.S. equivalents. This criterion effectively restricted studies to the Canadian prairie provinces, and the states of North and South Dakota, Montana, and parts of Wyoming.

Papers that met the above criteria were reviewed, and information related to the question of salt movement over time was summarized in tabular form for ease of comparison (see Table 4). Conclusions drawn by the author of the paper, as well as comments by the reviewer are included in the table. Wherever possible, actual data are presented in the summary table. For some larger, more complex studies, summarized information appears in Appendix 1.

In interpreting this review, it is important to keep in mind that a statistical significance of treatment results does not imply that a difference in salinity due to a treatment will or will not affect plant growth. For example, a difference in EC of 1 dS/m between treatments could be statistically significant, but would be unlikely to affect plant growth



1. Brown Soil Zone
2. Dark Brown Soil Zone
3. Black Soil Zone
4+5 Gray and Dark Gray Soil Zones

Figure 1. Major Soil Zones of Alberta.[a]

[a] Source: Adapted from Alberta Agriculture (1992)

appreciably if the change was from 0.2 to 1.2 dS/m. Conversely, a difference in EC of 5 dS/m may not be statistically significant because of data variability, but if the change was from 0.5 dS/m to 5.5 dS/m, growth of some crops could be affected.

3. RESULTS AND DISCUSSION

Results of the studies on salt movement are in disturbed soils are summarized in Table 4. Study objectives, location, disturbance type, soil type, time frame, landscape, land use, results, conclusions drawn by the authors of the study, and comments by the reviewer are included. A discussion and summary of results for Brown, Dark Brown, and Black soil zones follows.

3.1 BROWN SOIL ZONE

Several studies on pipelines in the Brown Soil Zone examined salt movement in soil over time. Naeth (1985) and Naeth et al. (1987) examined salt movement on a series of parallel pipeline trenches of different ages that were constructed on loam to clay loam soils without topsoil salvage. In a 2 year old trench, EC and SAR levels were much higher than controls at most depths. In an adjacent 11 year old trench, both EC and SAR remained higher compared to an adjacent undisturbed control, but most differences were small to a depth of 60 cm. Most differences disappeared in a 26 year old trench. Data for 1 of 3 sites monitored are presented graphically in Appendix 1. Live vegetative cover returned to near undisturbed levels within 26 years. However, species composition remained significantly different.

In a followup to the above study 10 years after construction of the youngest pipeline, Naeth (1993) found that EC levels were lower in 1991 compared to 1983 to a depth of 15 cm; EC remained higher than control levels at depths between 15 and 45 cm. SAR returned to control conditions within the 10 year period. Vegetation cover remained significantly lower on the 11 year old trench compared to the undisturbed control, but species composition on the trench was considered to be more palatable than species on the control.

Table 4. Summary of studies reviewed.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Ballantyne (1983)	Determine crop yield changes after deep plowing soils, and check soil changes for 5 years after deep plowing.	Radville Saskatch-ewan	Deep plowing to 61 cm	Dark Brown Solodized Solonetz and eroded Dark Brown Solodized Solonetz, moderately fine texture	5 years after plowing	Relatively level to gently undulating glacial till
Barth and Martin (1984)	Quantify soil depth requirements to maximize cool season grass production in Northern Great Plains strip mines.	2 mines in Montana and North Dakota	Strip mine	Not given	5 years	Slopes 1% to 3%
Buckland and Pawluk (1985)	Characterize changes in seedbed properties resulting from deep plowing.	East-central Alberta	Deep plowing to depths of 23 to 59 cm	Black and Dark Brown Solodized Solonetz, Black Solod, Orthic and Solonetzic Black Chernozem with various textures	4 and 5 years	Level to rolling and undulating to hummocky moraine

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Ballantyne (1983)	Cropped	EC (dS/m) year*/ 0 1 2 3 4 5 depth (cm) 0-15 1.1 2.3 1.8 1.9 2.3 2.2 15-30 1.5 1.5 2.8 2.2 2.2 2.4 30-46 3.0 2.8 2.9 2.9 3.6 3.6 46-61 4.4 4.2 4.8 4.2 5.6 5.1 61-91 6.0 5.8 6.2 6.3 7.2 7.0 91-122 6.6 6.7 7.0 6.6 7.9 7.3 SAR year/ 0 1 2 3 4 5 depth (cm) 0-15 8 5 5 6 6 5 15-30 11 7 7 8 9 9 30-46 11 8 8 10 9 10 46-61 11 10 10 12 11 10 61-91 13 11 11 14 12 10 91-122 14 11 12 15 13 11 * Year indicates number of years after deep plowing. Year 0 is pre-disturbance.	Average salinity at all sites was higher at year 5 than before disturbance; Reduction in Na^+ mainly due to increase in Ca^{++}. Deep plowing resulted in an increase in the average wheat yield each year.	No statistical significance given. SAR not given but was calculated from data presented. After 5 years, EC remained slightly higher than pre-disturbed conditions by less than 1 dS/m at all depths, but was also higher than EC at year 1. After 5 years, SAR was slightly lower than pre-disturbed conditions.
Barth and Martin (1984)	Forages	Significant amounts of Na^+ migrated 7 to 14 cm upwards into overlying soil 5 years after plot construction.	Average of 71 cm soil materials replaced over sodic spoil required to maximize revegetation.	Data for EC and SAR after 5 years were not presented in paper. Upward movement of sodium salts occurred from spoil material of SAR 28 into soil material of SAR 1. Both materials had fine loamy texture.
Buckland and Pawluk (1985)	Not given	EC (dS/m) Site/ 1+ 2+ 3+ 4x 5x tillage C 0.3 0.4 0.5 0.3 0.6 DP 1.1* 0.7 2.1* 1.2* 1.5* SAR C 1.3 1.0 5.5 3.7 4.9 DP 2.3 1.0 6.4 8.0* 8.6* * Deep plowed topsoil significantly different from control at $p=0.05$. o Dark Brown Soil Zone x Black Soil Zone C Adjacent conventionally tilled soil. DP Deep plowed.	Most sites responded to deep plowing with increased EC and SAR, but with varying levels of significance.	Time period was not sufficient to reduce EC and SAR levels in deep plowed soils, but initial levels immediately after deep plowing were not given.

Table 4. Continued.

Reterence	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Chang, Sommerfeldt, Schaalje, and Palmer (1986)	Determine effectiveness of subsoiling in amelioration of Brown Solonetzic soils and its effect on wheat yields under both irrigated and non-irrigated conditions.	Vauxhall, Alberta	Subsoiling to 52 cm	Solonetzic soils in the Brown Soil Zone, sandy loam surface overlying sandy clay loam to loam	3 and 4 years after plowing	Not given
DeJong and Button (1973)	Investigate the effects of pipeline installation on selected soils in southeastern Saskatchewan	South-eastern Saskatch-ewan	Pipelines 90 and 120 cm deep; topsoil probably not stripped.	Dark Brown and Black Chernozemic and Dark Brown Solonetzic soils, medium textured	8 to 10 years	Lower, mid and upper slope positions

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Chang, Sommerfeldt, Schaalje, and Palmer (1986)	Cropped (wheat)	EC (dS/m) non-irrigated plots trt*/ depth — 4 — 3 — Control 0-15 — 1.3 — 4.5 — 1.5 15-30 — 3.3 — 3.3 — 4.5 30-45 — 8.8 — 9.0 — 10.6 45-60 — 11.5 — 11.3 — 13.0 60-90 — 12.6 — 11.9 — 13.0 SAR 0-15 — 1.3 — 1.5 — 1.4 15-30 — 3.6 — 3.2 — 3.7 30-45 — 7.1 — 5.4 — 7.6 45-60 — 12.5 — 10.0 — 12.9 60-90 — 17.3 — 15.6 — 15.0 * trt indicates number of years after subsoiling. All samples monitored in same year. No significant differences between disturbed and controls.	Soil salinity lower in irrigated field than in non-irrigated field, but no significant differences between tillage treatments in non-irrigated field. No yield differences between tillage treatments in either irrigated or non-irrigated fields.	Initial soil EC and SAR immediately after subsoiling was not known. It was not known whether the lack of differences between subsoiled and non-subsoiled plots was due to salt movement over the time period, or due to lack of initial differences resulting from subsoiling.
DeJong and Button (1973)	Cropped	EC (dS/m) Soil — Age (years) — depth (cm) — undisturbed — trench minus undisturbed 1 — 1-2 — 0-15 — 0.8 — 2.2* — — 15-30 — 1.1 — 2.7* — — 30-60 — 2.9 — 1.8* 1 — 8-10 — 0-15 — 0.8 — 1.3* — — 15-30 — 1.1 — 0.7 — — 30-60 — 2.9 — -1.2 2 — 1-2 — 0-15 — 1.0 — 3.6* — — 15-30 — 1.6 — 4.4* — — 30-60 — 4.8 — 1.6 2 — 8-10 — 0-15 — 1.0 — 1.4 — — 15-30 — 1.6 — 0.6 — — 30-60 — 4.8 — -1.5 3 — 2-3 — 0-15 — 1.2 — 3.1* — — 15-30 — 3.3 — 1.8 — — 30-60 — 5.8 — -0.6 3 — 9-11 — 0-15 — 1.2 — 0.3 — — 15-30 — 3.3 — -0.7 — — 30-60 — 5.8 — -1.1 * trench is significantly different from control at $p \leq 0.10$ When sampled 1 to 3 years after construction, increases in EC within the root zone remained on all three pipelines. When sampled 8 to 11 years after construction, there were differences between trench and undisturbed only at 0-15 cm depth on one site.	With time, some salts will leach out. Pipeline construction improved physical properties of Solonetzic or Solonetzic-like soils. Yields on recently installed pipelines in Solonetzic soils did not differ significantly from undisturbed controls, and on older pipelines, yield increases were observed.	SAR not reported. Only data for Solonetzic and Solonetzic-like soils have been summarized here.

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Dollhopf, Wendt and Levine (1980)	Examine the effects of chemical amendments and irrigation on sodium salt migration within the reconstructed soil profile.	Montana	Strip mine	Not given	2 years	Nearly level
Emerson, Baker and Fedenczuk (1993)	Compare upper trench salinity for pipelines constructed in 1972, 1975, and 1990 as a function of time since construction, and compare trench salinity to off-RoW B horizon salinity.	Various locations along North Lateral Pipeline in central Alberta	Pipeline, no trench depths presented. 17 and 20 year old pipelines were 2 lifted, 2 year old pipeline was 2 and 3 lifted.	Orthic Dark Brown and Black Chernozemic soils with saline C horizons, with various textures	3 pipelines 2, 17, and 20 years old	Not given
Finlayson and Cannon (1993)	Determine if any long-term differences in soil quality or range productivity exist between a pipeline RoW constructed on native rangelands using four depths of topsoil stripping, and an adjacent control area.	5 km north of Youngs-town, Alberta	Pipeline, 2 lifted	Orthic Brown Chernozemic and Brown Solodized Solonetzic soils on coarse loamy glaciofluvial veneer overlying till	3 years	Nearly level

Table 4. Continued.

<table>
<tr><th>Reference (continued)</th><th>Land Use</th><th>Results</th><th>Author's Conclusions</th><th>Comments</th></tr>
<tr><td>Dollhopf, Wendt and Levine (1980)</td><td>Forages</td><td>After 2 years, there was little change in SAR (originally below 5) and EC (originally below 1 dS/m) of the upper 35 cm of replaced soil materials. EC and SAR increased gradually between 35 and 70 cm depth, just above the soil/spoil interface in the same time period.
Below 70 cm, SAR decreased over time, from an average of about 21 to an average of about 16. EC increased from about 4 to less than 5.</td><td>Little effect of irrigation or chemical amendments on salt movement in soil profiles in most cases .
No evidence of upward movement of salts into topsoil from spoil.</td><td>Replaced "topsoil" was 70 cm thick, non-saline and non-sodic.
Results given are for non-amended, non-irrigated treatment.
Numerical data were not presented in paper; values were read from graphs.</td></tr>
<tr><td>Emerson, Baker and Fedenczuk (1993)</td><td>Not given</td><td>Mean EC (dS/m) for trench spoil below topsoil and above 50 cm, by year of construction:

Control 1990 1975 1972
1.37 5.15 2.13 2.49</td><td>EC of trench was significantly higher in the 1990 trench than in either older trench. Initial EC value of the 3 trenches was unknown. However, statistical modelling indicated differences between 1990 trench and the older trenches were significant.</td><td>Statistical significance of differences between trenches and undisturbed controls were not reported in this study.
Differences in SAR were not determined in this study.
This was a preliminary draft report.</td></tr>
<tr><td>Finlayson and Cannon (1993)</td><td>Native rangeland</td><td>EC (dS/m)
Trt+ / Depth (cm) / Pre-construction / Trench (year 3)
0 cm / 0-10 / 0.7 / 3.2*
10-30 / 0.8 / 5.5*
30-60 / 5.5 / 7.2
60-100 / 7.0 / 6.9
10 cm / 0-10 / 0.5 / 0.6
10-30 / 0.2 / 1.8*
30-60 / 3.1 / 3.9
60-100 / 8.7 / 5.3*
20 cm / 0-10 / 0.5 / 1.3
10-30 / 1.0 / 1.2
30-60 / 5.5 / 2.8
60-100 / 7.9 / 5.6
30 cm / 0-10 / 0.4 / 0.7*
10-30 / 0.7 / 1.1
30-60 / 6.2 / 4.3
60-100 / 8.0 / 5.0
* statistically significantly different from pre-construction at p=0.05
+ trt is depth of topsoil stripping

Elevated EC occurred within the root zone in all but the 20 cm topsoil stripped treatment.
Where differences in SAR between pre-construction and year 3 occurred, year 3 values were lower than pre-construction.</td><td>There was a general trend for trench EC to return to pre-construction or control EC values after 3 years.
Below 30 cm depth there was a general trend for trench SAR to become lower than pre-construction or control SAR levels after 3 years.
Biomass remained lower on 0 cm treatment (152 g/m^2) compared to 10, 20, and 30 cm treatments (291, 326, and 301 g/m^2) respectively.</td><td>This is an draft, annual report; the project will continue for at least 5 years.</td></tr>
</table>

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Graveland and Fujikawa (1976)	Determine changes in soils of a strip-mined area.	Ryley-Camrose area, Alberta	Strip mine	Eluviated Black Chernozem and Black Solodized Solonetz on glacial till	Sites disturbed in 1920's, 1950's and 1960's.	Not given
Graveland, Oddie, Osborne, and Panek (1988)	Determine the optimum depth of subsoil replacement over sodic minespoil to ensure adequate crop productivity Assess sustainability of crop production on soil replaced over sodic minespoil by monitoring upward soluble salt migration into the root zone.	Highvale Mine, west of Edmonton Alberta	Strip mine	Solonetzic, Luvisolic, Gleysolic, Brunisolic, and Organic soils occur in mine area, in Black to Dark Grey soil zones.	5 years	Levelled
Harker, Webster, and Cairns (1977)	Determine effects of deep-plowing a Solonetz soil on the growth of an alfalfa-brome mixture and on the properties of a soil.	Chipman, Alberta	Deep-plowing to 50 cm depth	Black Solonetz on fine textured lacustrine	7 years	Not given

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Graveland and Fujikawa (1976)	Naturally revegetated grass and aspen trees	EC was significantly higher on disturbed areas compared to adjacent undisturbed areas in 0 to 15 cm increment only (1.73 and 0.60 dS/m respectively). SAR was very low on all disturbed sites.	Increase in EC in 0 to 15 cm depth did not affect natural revegetation.	Methods not clearly outlined. It appeared that data from disturbed areas were lumped together regardless of age. No data were given for revegetation.
Graveland, Oddie, Osborne, and Panek (1988)	Forage and cropped	No differences in EC over time were found, but values were consistently low (ranging from 0.1 to 1.1 dS/m). SAR was significantly higher immediately above the soil/spoil contact for the 3.45m subsoil thickness treatment by year 2 (2.9) compared to year 1 (0.7), and persisted under forages to year 5 (4.8). Under barley, SAR was significantly higher above the soil/spoil contact for 1.35m subsoil thickness by year 4 (9.6) compared to year 1 (1.2), and persisted to year 5 (7.5), possibly indicating some upward sodium movement from spoil into soil. Barley and forage yields generally increased over time.	EC values remained low and were not considered a detrimental factor in crop productivity. SAR values increased above the subsoil/spoil contact, concentrated primarily within the 15 cm increment immediately above the contact. It was not known if additional upward migration or downward flushing of salts with more precipitation would occur over a greater time period.	Soil chemical parameters were measured immediately above the subsoil/ minespoil interface, which occurred at depths ranging from 0.55m to 3.45m. Initial soil materials were non-saline and non-sodic; spoil materials were non-saline but sodic, with SAR of 20.
Harker, Webster, and Cairns (1977)	Forages	Tillage / Horizon or zone / EC (dS/m) Normal / A / 2.1 DP / surface / 4.8* Normal / B / 4.1 DP / middle / 9.1* Normal / C / 10.6 DP / C / 11.2 Normal - conventional tillage DP - deep plowed * significantly different at $p=0.01$ After 7 years, EC of deep-plowed A and B horizons was significantly higher than undisturbed controls. After a single rainfall event of 14 cm, EC of deep-plowed A horizon was reduced to 3.6 dS/m, which was not significantly different from the control.	Forage yields remained significantly higher on deep plowed plot compared to undisturbed control after 7 years.	A single heavy rainfall reduced EC in upper profile of disturbed soil, but it is not known if it subsequently re-salinized, or was a permanent change. SAR was not considered in this study.

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Iverson and Wali (1982)	Document changes in plant species composition and in physical and chemical properties of soils in the first 4 years after reclamation.	South of Beulah, North Dakota	Strip mine	Typic Haploboroll (Chernozemic soil)	4 years	Not given
Knapik, Cannon, and Harron (1990)	Monitor and assess the effects of 2 and 3 lift soil handling procedures in pipeline construction activities on land quality and crop yields on saline-sodic soils.	Standard-Hussar area in Alberta, 75 km E of Calgary	Pipeline to 140 cm	Inter-mixed Dark Brown Solodized Solonetz and Solonetzic Dark Brown Chernozems on clayey glacio-lacustrine veneer overlying glacial till	5 years	Undulating to rolling morainal plain

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Iverson and Wali (1982)	Native mixed grass prairie	EC (dS/m) of topsoil (0 to 15 cm) Years after Mining 1 2 3 4 Unmined 3.1b* 2.1ab 2.4ab 1.2ab 0.3a * Numbers with the same letter following are not significantly different from one another. One year after reconstruction, EC of disturbed topsoil was significantly higher than unmined control. This significant difference disappeared in the second year.	No specific conclusions drawn by authors about soil properties. After 3 years, seeded wheatgrasses increased to dominance, and invading kochia decreased rapidly.	Mainly a vegetation study. Only top 15 cm of soil analyzed.

Knapik, Cannon, and Harron (1990)	Cropped	EC (dS/m)
		Site Depth (cm) Control 2-lift Trench 3-lift Trench
		1 0-10 0.7 0.7 0.7
		  10-20 0.7 0.8 0.6
		  20-30 1.0 1.2 0.9
		  30-50 1.1 2.1 1.5
		2 0-10 1.4 1.7 1.9
		  10-20 0.7 1.4* 2.6*
		  20-30 0.7 2.0 2.2
		  30-50 1.2 4.4* 4.1*
		3 0-10 1.4 2.5* 1.6
		  10-20 0.9 1.4* 1.2
		  20-30 1.0 2.3 4.2*
		  30-50 2.0 6.3* 6.7*
		* Significantly different from control at $p \leq 0.05$.
		
		After 5 years, differences in trench EC remained within the 0 to 50 cm depth for 2 of 3 sites. Some of these differences had disappeared in previous years, but re-appeared in the final year of sampling.
		After 5 years, SAR values were equal to or lower than controls at all sites and all depths.
		No statistically significant difference between trench and control wheat yields after the first year.
			Negative effects on soil quality due to salinity and sodicity persisted for 2 to 3 years but were not a problem at 5 years.	No statistical comparisons between years were given.
				Crop yield data was incomplete.
				This was a preliminary draft report.

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Leskiw (1989)	Determine minimum thickness of subsoil to be replaced over sodic mine spoil. Determine whether upward migration of salts would take place, and how serious a problem this could be.	20 km north of Halkirk, Alberta	Strip mine	Orthic and Solonetzic Dark Brown Chernozems, Dark Brown Solodized Solonetz, and intergrades	5 years	Levelled spoil
McAndrew and Malhi (1990)	Determine the long-lasting effects of deep plowing on soil chemical characteristics and crop yield of Solonetzic soils.	4 sites in east-central Alberta at Donalda, Heisler, and Vegreville.	Deep plowing 50 to 70 cm deep	Black Solodized Solonetz, thin Black Solod, Black Solonetz, Orthic and Eluviated Black Chernozem, on glacial till or lacustrine	4 sites 11, 12, 20, and 29 years old	Not given
Merrill, Doering, and Power (1980)	Analyze examples of salinity and sodicity changes observed in experiments.	North Dakota	Strip mine, 12 inches (30cm) topsoil replaced	Not given	4 years	Not given

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Leskiw (1989)	Forages and grains	In 5 years, significant linear decline in topsoil EC by nearly 1/2 from a range of 3.2 to 3.5 dS/m, to a range of 1.5 to 1.7 dS/m; no differences in upper subsoil EC over time (average 5.8 dS/m); lower subsoil EC increased from 6.7 to 8.5 dS/m. Linear decline in topsoil SAR over 5 years, from a range of 3.5 to 5 at year 1 to a range of 1 to 2 at year 5; no differences in SAR between years 1 and 5 in upper subsoil (average 8.3), lower subsoil (average 13.2), or spoil (average 27).	Topsoils in treatments with subsoils over spoils showed marked improvement in topsoil quality, mainly in the first two years; upper subsoils initially degraded or remained unchanged, then improved the last two years; both effects are due to leaching of salts from the upper profile. Salt accumulation occurred in the lower profile, the depth being governed by the depth to spoil.	Plots consisted of 15 cm topsoil over varying depths of subsoil ranging from 0 to 332 cm in subsoil depth experiment. Forage and grain yields were significantly lower in year 5 compared to year 1, probably due to drought.
McAndrew and Malhi (1990)	Forages and grains	EC (dS/m) SAR Site depth(cm) C DP C DP 1 0-12 1.9 1.6* 5.3 6.0 (12 yrs) 12-30 2.7 2.5 13.4 10.0* 30-60 5.2 4.0 14.7 12.7 60+ 3.9 5.2* 12.7 16.3 2 0-12 2.5 2.0* 7.0 5.6* (11 yrs) 12-30 3.8 3.9 13.8 10.4* 30-60 6.1 5.9 16.1 13.4* 60+ 5.9 6.6 18.1 17.2 3 0-12 2.3 2.3 6.4 5.0 (20 yrs) 12-30 5.9 4.5 12.9 8.0* 30-60 10.9 7.2* 15.6 11.0* 60+ 12.5 8.8* 20.0 13.3* 4 0-12 1.2 0.9 8.5 1.3* (29 yrs) 12-30 2.5 0.9 13.6 2.6* 30-60 3.8 3.0 16.1 8.2* 60-90 4.8 5.0 17.5 17.8 90-120 5.5 5.7 20.1 20.1 * significantly different from control, $p=0.05$ C Control DP Deep plowed	Deep plowing had long-term beneficial effect on forage crop production. Authors have drawn no conclusions on salt movement.	Soil chemistry immediately after deep plowing was not presented. At site 1, EC of disturbed soil remained higher than control only at 60+ cm depth. At sites 2 to 4 for EC and all sites for SAR, disturbed soil was lower than control wherever differences were significant.
Merrill, Doering, and Power (1980)	Forages	SAR increased at all 4 sites in lower topsoil (6 to 12 in. depth). SAR of subsoil (12 to 36 inches) after 4 years was similar to initial values which ranged from 11 to 27 $\pm$ 2.	Potential for upward movement of sodium salts into better quality topsoil is higher where spoil is dispersed, material has very low hydraulic conductivity, SAR values are >20, and there is 30 cm or less of non-saline material overlying spoil	Paper included a model for upward diffusion of salts from spoil into topsoil.

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Merrill, Doering, and Sandoval (1983)	Compare the efficacy of and observe the interactions among the reclamation techniques of topsoil overspreading, gypsum application and multi-year fallowing applied to minespoils ranging in quality from nonsodic to highly sodic.	West-central North Dakota	4 strip mines within 60 km of each other	Moderately fine textured, moderately saline Borolls (Chernozemic soils)	4 and 5 years	Minespoils graded to roughly level contour
Naeth (1985); Naeth, McGill, and Bailey (1987)	Document and assess responses to pipeline installation in solonetzic mixed prairie rangeland and study the longevity of responses.	10 km east of Princess, Alberta	Pipeline corridor of 5 adjacent natural gas pipelines, 2.5m deep and 3m wide, all constructed without topsoil salvage	Brown Solodized Solonetz, and Brown Solod, loam to clay loam texture	5 pipelines, 2, 11, 15, 20, and 26 years old	Undulating moraine with slopes <2%.

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Merrill, Doering, and Sandoval (1983)	Forage (crested wheat-grass)	SAR Plots with no topsoil, 0 to 15 cm depth sites/time: 1, 2, 3 3 months: 12.8, 8.9, 19.6 4,5 yrs: 8.3, 6.8, 16.1 Plots with topsoil, 30 to 60 cm depth 3 mos: 11.9, 10.6, 27.9 4,5 yrs: 10.7, 9.7, 25.2 In plots without topsoil, average SAR of the 0 to 15 cm depth increment decreased from 13.7 to 10.4 in 4 to 5 years. In plots with 30 cm of topsoil, average SAR of the 30 to 60 cm depth increment decreased from 16.8 to 15.2 in 4 to 5 years.	No conclusions specific to salt movement in unamended soil were given.	No data given for EC. Statistical significance of differences in SAR between years was not given. Effect on forage yield of decrease in soil salinity and sodicity over time was not examined.
Naeth (1985); Naeth, McGill, and Bailey (1987)	Solonetzic mixed prairie rangeland with spring and fall grazing regimes	EC of 2 year old trench was significantly higher than undisturbed control at all depth increments. EC of 26 year old trench was not significantly different from the control except for the 60 to 75 cm depth increment where the 26 year old trench was significantly higher than the control. SAR of 2 year old trench was higher than that of undisturbed control to 30 cm. Below 30 cm, there were no differences in SAR between trenches. Live vegetation cover was 5% on the 2 year old trench, 40% on the 26 year old trench, and 50% on the undisturbed control.	There appeared to be a trend towards predisturbed conditions within 9 years of disturbance, but more than 24 years was needed for a complete return to predisturbed chemical conditions. Within 26 years, amount of live vegetation on trench had returned to near pre-disturbance conditions, but species composition remained significantly different.	Soil data are presented graphically in Appendix 1.

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Naeth (1993)	Examine effects of pipeline construction on ground cover and plant species composition, soil chemical properties, and soil physical properties on pipelines of 2 different ages.	10 km east of Princess, Alberta	2 pipelines in a corridor, up to 2.5m deep, constructed with no topsoil salvage.	Brown Solodized Solonetz, and Brown Solod	35 and 11 years	Undulating moraine with slopes <2%.
Richardson and Farmer (1982)	Determine effects of various soil amendments on production of vegetation and the relative proportion of Na^+ to other cations in soils.	Southeast Montana (north of Sheridan, Wyoming)	Strip mine	Not given	7 years	Level graded spoil materials
Riddell, Webster, and Hermans (1988)	Determine if deep ripping alters selected soil SAR, EC, pH, by physically lifting salts from salt-enriched subsoil horizons.	Halkirk, Alberta	Deep ripping to 35 to 45 cm	Dark Brown Solodized Solonetz on till and residual	4 to 5 years, 2 fields	Level to gently undulating

Table 4. Continued.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Naeth (1993)	Rangeland with spring and fall grazing regimes	EC 1981 Trench Monitored in: depth (cm) / 1983 / 1991 / control 0-5 / 3.3 / 1.9* / 0.4 5-15 / 5.1 / 4.5*+ / 0.2 15-30 / 5.9 / 6.7+ / 0.8 30-45 / 6.3 / 8.7+ / 2.1 45-60 / 7.7 / 7.5 / 3.2 60+ / 7.1 / 7.1 / 3.3 *statistically different from 1983 trench at p=0.05 +statistically different from control at p=0.05 SAR*+ 1981 Trench Monitored in: depth (cm) / 1983 / 1991 / control 0-5 / 4.0 / 1.5 / 0.3 5-15 / 6.6 / 4.9 / 1.7 15-30 / 8.1 / 10.0 / 6.6 30-45 / 10.0 / 14.6 / 11.6 45-60 / 11.4 / 12.5 / 13.2 60+ / 10.4 / 10.6 / 12.1 *no statistical significance given for comparison of trench in 1983 and 1991 +no statistical difference between trench in 1991 trench and control at p=0.05	There was a distinct trend towards predisturbed conditions evident in soil chemical parameters. Downward salt movement had occurred in the 10 year old trench and stockpile as evidenced by decreases in EC and SAR. Pipeline construction had significant effects on soil chemical, soil physical, hydrologic, and vegetative parameters of the ecosystem. There is a distinct long term trend towards predisturbed conditions evident in vegetation and soil chemical and physical characteristics.	This study was a follow-up study to Naeth (1985). After 10 years, trench EC between 5 and 45 cm depth had not yet approached control values. However, trench SAR was similar to control SAR after 10 years. Vegetation cover % was significantly higher on the control (87%) compared to the 10 year old trench (36%). Species composition was generally more palatable on the trench compared to the control. This was a preliminary draft report.
Richardson and Farmer (1982)	Seeded to native and agron-omic forage species	SAR consistently decreased throughout 7 years (from 12 to 3 or less), with most decreases occurring in the first 5 years. Forage biomass increased consistently over the 7 years.	Relative proportion of Na to other cations decreased with time. Decreases were attributed to leaching of Na^+ by percolating water from rain and snow.	No actual data or means were given, but a regression was derived with SAR as a function of time and biomass production.
Riddell, Webster, and Hermans (1988)	Cropped	No significant difference in SAR between deep ripped field and undisturbed control in either field. Decrease in EC in ripped Csk (2.8 dS/m) compared to control (4.0 dS/m) in one field only.	Ripping resulted in changes to soil chemical properties in one field only, attributed to both physical lifting of subsurface material, and capillary moisture movement.	No data for conditions immediately after ripping, so it was not known if salt content decreased over time, or was low to begin with.

Table 4. Continued.

Reference	Objectives	Location	Disturbance Type	Soil Type	Time Frame of Study	Landscape
Sandoval, Bond, and Reichman (1972)	Determine the effect of deep plowing and amendments on soil water relationships, physical and chemical soil properties and crop yield on a sodic claypan soil	Western North Dakota	Deep plowing to 15, 30, and 61 cm	Leptic Natriboroll (Solodized Solonetz) silt loam to silty clay loam	5 years	1% to 2% slope
Wetter, Webster, and Lickacz (1987)	Determine the effect of subsoiling and liming on selected physicochemical characteristics related to agronomic productivity, moisture, and crop yields.	15 km south of Halkirk, Alberta	Subsoiling	Dark Brown Solodized Solonetz, clay loam to clay textured, on glacial till veneer overlying residual	1 year	Level to slightly undulating

Table 4. Concluded.

Reference (continued)	Land Use	Results	Author's Conclusions	Comments
Sandoval, Bond, and Reichman (1972)	Cropped	Deep plowing significantly increased salinity at 0 to 15 and 15 to 30 cm depth increments initially, to EC of 5.8 and 5.7 dS/m respectively, but decreased over 5 years, to 1.8 and 2.3 dS/m for the same depths.	Deep plowing increased barley and wheat yields, apparently due to increased soil water availability.	Information on deep plowing to 24 cm only was considered here. Effect on vegetation of the decrease in salinity over time was not examined.
Wetter, Webster, and Lickacz (1987)	Cultivated	SAR subsoiled control Ap 5.2 4.4 Bnt 6.2* 12.7 BC 9.3* 12.8 Cca 11.2 13.4 * SAR significantly different from control Subsoiling resulted in a significant decrease in SAR in the Bnt and BC horizons only.	Differences between treatments were attributed to subsoiling, which increased both grain and straw yield. No evidence of subsoiled plots reverting to pre-subsoiled conditions.	No EC data were presented. Since SAR values immediately after disturbance were not known, it could not be determined if lower SAR values after 1 year was due to salt movement over time, or because initial values were lower.

In a study of a pipeline constructed in moderately coarse to coarse textured soils, EC levels in treatments with topsoil stripping were close to or lower than pre-construction levels after 3 years. The topsoil that was stripped and replaced never had elevated EC levels. In the subsoil, initial increases had disappeared after 3 years. In the treatment with no topsoil salvage, 3 years was not sufficient time for elevated EC levels to return to pre-construction conditions in the top 30 cm of the reconstructed soil profile. Below 30 cm, initial increases in EC had disappeared after 3 years on the treatment with no topsoil stripping. After 3 years all initial differences in SAR had disappeared in all treatments (Finlayson and Cannon 1993). Forage biomass on the treatment with no topsoil stripped remained lower than on the other treatments where topsoil was stripped.

Results from one deep plowing study in the Brown Soil Zone are inconclusive. After 4 and 5 years, no differences in EC were found between deep plowed plots and adjacent conventionally tilled land, in sandy loam to sandy clay loam textured soils (Chang et al. 1986). However, since EC was not measured immediately after disturbance in this study, it was not known if deep plowing had resulted in an initial increase in EC. There were no differences in grain yields between tillage treatments.

To summarize, in the Brown Soil Zone, SAR appears to return to normal pre-construction conditions more quickly than EC. In coarse to moderately coarse textured soils, 5 years may be sufficient time to return soil EC and SAR to pre-construction conditions. In medium to moderately fine textured soil, the return to normal conditions, particularly for EC, is slower. The time required for EC to return to pre-construction conditions in medium to moderately fine soils appears to be between 10 and 26 years on pipelines with no topsoil salvage; there are no data available for pipelines constructed with topsoil salvage. SAR may return to pre-construction conditions in 10 or less years. Up to 26 years may be required for the return of live vegetative cover to undisturbed conditions after pipeline trench construction. Where agronomic species are seeded, palatability may be increased on the trench compared to the undisturbed control. Topsoil salvage in the Brown Soil Zone, as currently practised, appears to be effective in preserving the quality of topsoil material.

3.2 DARK BROWN SOIL ZONE

Two pipeline studies in the Dark Brown Soil Zone examined salt movement over periods of time ranging from 1 to 11 years after construction. DeJong and Button (1973) found that, after 1 to 3 years, trench EC values were higher than undisturbed controls in all Solonetzic sites examined. However, on pipelines constructed 8 to 11 years previously through the same soils, they found no differences between trench and controls. It is therefore likely that EC values reached acceptable levels in 3 to 8 years. No crop yield differences between trench and control were reported on 1 to 3 year old pipelines. Yields on older pipeline trenches were higher than on controls. The authors noted that pipeline construction improved soil physical properties on pipeline trenches in Solonetzic areas, which would result in the leaching of some salts. However, they could find no clear relationship between soil physical properties and crop yields due to the interdependence of these properties.

Knapik et al. (1990) found that after 5 years, trench EC remained higher than controls at some depth increments for 2 of 3 sites, in both 2-lift and 3-lift treatments. Differences ranged from 0.3 dS/m to 4.7 dS/m. All trench SAR values were equal to or lower than controls after 5 years. It should be noted that some of the differences in EC occurring between trench and controls in year 5 had not been present in previous years. No differences in wheat yields between trench and control in any treatment were reported.

In the only mining study in the Dark Brown Soil Zone, Leskiw (1989) found a significant linear decline in topsoil EC and SAR over a 5-year period, to less than half the original values. On the other hand, in upper subsoil (15 to 35 cm depth), there were no changes over 5 years in EC or SAR. There were no undisturbed controls or pre-disturbance data available in this study. Despite a decrease in topsoil EC and SAR over time, forage and grain yields were lower in year 5 than in year 1, possibly due to drought.

Results of deep plowing and deep ripping studies are inconclusive. Ballantyne (1983) found that slight increases in EC persisted after 5 years in deep plowed sites compared to undisturbed controls, but differences were generally small. Deep plowing resulted in an increase in wheat yields. Two other deep ripping studies (Riddell et al. 1988; Wetter et al. 1987) reported no differences in SAR between deep ripped plots and adjacent conventionally tilled controls after 1 to 5 years. In these two studies, differences in SAR immediately after disturbance were not known. Vegetation was not assessed in either of these two studies.

To summarize, in the Dark Brown Soil Zone, 1 to 3 years appears to be insufficient time to allow elevated soluble salt content of disturbed soils to return to levels which would be comparable to pre-construction or control conditions. On the other hand, 8 to 11 years appears to be more than sufficient. It is likely that 5 years is a marginal time period, being sufficient under some conditions, but not sufficient under others. Unfortunately we do not have the data at present to determine what these conditions might be. Differences in crop response between studies indicates that factors other than EC and SAR may be affecting or controlling yields, or increases in salinity or sodicity were not sufficient to result in yield differences for the particular crop measured.

3.3 BLACK SOIL ZONE

No studies dealing with salt movement on reclaimed pipelines in the Black Soil Zone were found, but there were several deep plowing and mine reclamation studies. One deep plowing study found that 4 and 5 years were not sufficient to return elevated EC and SAR values to control levels in topsoil (Buckland and Pawluk 1985). Differences in topsoil EC levels were less than 1 dS/m; differences in topsoil SAR values averaged 4. Vegetation was not evaluated in this study. In another study, Harker et al. (1977) found that after 7 years, EC was higher in the A and B horizons of deep plowed soils compared to conventionally tilled soils by 2.7 and 5 dS/m respectively. Despite this increase, forage yields remained higher on deep plowed plots compared to undisturbed controls. They noted, however, that topsoil salinity levels decreased after a single heavy rainfall of 14 cm. McAndrew and Malhi (1990) found that slightly increased EC levels remained in deep plowed plots which were 12 years old, compared to conventionally tilled controls, at depths of >60 cm. No increases in EC were found at sites which had been deep plowed 11, 20 and 29 years previously; in some cases decreases in EC were reported. EC values for the deep plowed plots immediately after disturbance are not known. In general, deep plowing had long-term beneficial effects on forage production in this study.

Two studies examined salt movement in reclaimed strip mined land in the Black Soil Zone. Graveland and Fujikawa (1976) found that various untreated spoils 15 to 50 years old had higher EC compared to undisturbed controls. However, EC values of spoils and controls were below 2 dS/m, and spoils were non-sodic. They did not further analyze the data by age. Vegetation parameters were not assessed. Graveland et al. (1988), found no change in EC over 5 years in a 15 cm depth increment immediately above the soil-spoil interface, but found increased SAR in two of the subsoil depth treatments. EC remained low (0.1 to 1.1 dS/m) throughout. Some upward movement of sodium from spoil into soil was indicated. Crop yields generally increased over time.

To summarize, data for the Black Soil Zone are insufficient to draw firm conclusions. Since none of the deep-plowing studies measured salinity levels immediately after deep plowing, it is difficult to draw any conclusions about salt movement within disturbed soil profiles over time. One deep plowing study found that the EC of deep plowed plots were similar to or lower than undisturbed controls when measured 11 to 29 years after disturbance. Other studies measured higher EC and SAR values on deep-plowed plots compared to controls 4 to 7 years after deep plowing. EC and SAR values in the two mine spoil studies were low to begin with; hence it was difficult to draw firm conclusions about salt movement over time. The increased SAR at the soil-spoil interface that was found in one mining study is likely due to diffusion across an abrupt salt concentration gradient. Since salinity and sodicity levels were near control levels in these studies, or were low to begin with, it is not surprising that no negative effects on vegetation were reported.

3.4 U.S. PAPERS WITH UNKNOWN SOIL ZONE

A number of studies on strip mines in North Dakota and Montana were included in this review. It was not possible to assign a soil zone to them, because the U.S. system of soil classification does not recognize soil zones as does Alberta. Most were likely Brown or Dark Brown soils, but this cannot be confirmed by information presented in the papers.

A number of U.S. studies examined salt movement downward through reconstructed soil profiles at reclaimed mines. Results were not consistent. However, decreases in topsoil SAR after 5 years were noted by Merrill et al. (1983), with an average decrease of 3.3; subsoil SAR decreased an average of 1.6 over the 5 year period. Neither of these two studies examined changes in crop yields on unamended soils. Larger decreases in SAR of up to 15 over 7 years were reported by Richardson and Farmer (1982) in the upper 30 cm of the soil profile. They found that forage biomass increased over the same time period. Dollhopf et al. (1980) found that after 2 years, there was little change in SAR and EC of the upper 35 cm of replaced soil materials. They found that EC and SAR increased gradually between 35 and 70 cm, just above the soil-spoil interface, in the same time period. Below 70 cm, SAR decreased over time. No relevant vegetation information was presented.

A number of studies examined soil materials immediately above a soil-spoil interface in order to determine whether upward diffusion of salts occurred from saline spoil into the overlying non-saline soil. Merrill et al. (1980) found that SAR increased in the 15 to 30 cm increments of four reconstructed soils, where non-sodic soil material had been replaced over sodic spoil materials with SAR values ranging from 11 to 27. In the 15 to 30 cm increments, the original SAR values, which ranged from 1 to 3, increased to a range of 4 to 18 after 4 years, an increase the authors attributed to salt movement by diffusion. Barth and Martin (1984) found that significant amounts of Na^+ had migrated 7 to 14 cm upward into non-saline soil 5 years after plot construction. Both soil and spoil materials were fine-loamy in texture, with SAR values of 1 and 28 respectively. Dollhopf et al. (1980), on the other hand, found no upward movement from a sandy clay loam to clay loam subsoil with SAR of 23, into overlying sandy loam soil material within 2 years. Degradation of topsoil due to the upward movement of salts by diffusion across a strong salt gradient in a reconstructed soil on a pipeline has not been documented. However, such degradation could occur where dispersed spoil materials with very low hydraulic conductivity and SAR values >20, overlie 30 cm or less of non-saline soil material.

In a deep plowing study, Sandoval et al. (1972) found that EC values for the 0 to 15 cm and 15 to 30 cm depth increments, which increased initially after deep plowing, decreased after 5 years by 4.0 and 3.4 dS/m respectively for the two depth increments. Effect on vegetation of the decrease in salinity over time was not examined.

To summarize, because many of these studies had objectives other than monitoring salt movement through the soil, relevant data were sparse and inconsistent. Many of the mining studies had no pre-disturbance data or undisturbed controls and looked only at net changes in salt content over time. Most reported some decrease in EC or SAR over relatively short periods of time, but the magnitude of the decrease varied from study to study. Upward movement from a mine spoil-soil interface was reported in some studies. A similar upward movement could occur in a pipeline reclamation situation if the conditions necessary for a strong salt gradient within the reconstructed soil profile are met. Most studies did not report relevant vegetation data. However in one study, forage biomass increased over 7 years as SAR decreased by 15.

4. CONCLUSIONS

1. The body of available knowledge on the movement of soluble salts through disturbed soils is meagre, particularly with respect to studies dealing specifically with pipeline construction. There were no pipeline studies at all in the Black Soil Zone.
2. Most authors agreed that soluble salt content of salinized disturbed soils decreases over time. However, the length of time required for soils to return to a level comparable to pre-construction or undisturbed conditions varied widely from study to study.
3. In the Brown Soil Zone, 5 years may be sufficient for EC and SAR to return to pre-construction conditions in coarse to moderately coarse soils. In finer textured soils, more than 10 years appears to be required for EC to return to pre-construction conditions. However, 10 years is likely more than sufficient for SAR to return to normal. In the Dark Brown Zone, 5 years is marginal for some soils to return to pre-construction conditions. Rates of salt movement through disturbed soils in the Black Soil Zone are probably similar to or more rapid than in the Dark Brown Soil Zone. Unfortunately, the body of available data was poor, and results inconclusive.
4. Data were insufficient to draw firm conclusions about the effects of soil texture on rates of salt movement. There was some indication that coarse textured soils return to pre-disturbed levels more quickly than finer textured soil.
5. Although a few papers mentioned changes in salt concentration after a single heavy rainfall, or noted that salts increased in some years and decreased in others, no studies were found which documented seasonal changes in salt distribution through disturbed soils. Seasonal variability of salt distribution within a soil profile is not considered in the 3-lift guidelines.

6. Upward movement of salts from strongly saline spoil material into non-saline subsoil or topsoil was documented in a number of mine reclamation studies, but not in any of the pipeline reclamation studies. Upward movement of salts could occur in a reclaimed pipeline, but is not likely to be a problem in many situations since the necessary salt gradient between spoil and topsoil is probably less common in the relatively shallow disturbances associated with pipeline construction compared to strip mines.
7. Data were insufficient to assess whether Alberta's existing 3-lift guidelines adequately account for differences in soil zone.
8. The effects on plant growth of changes in EC and SAR over time is difficult to isolate from other factors affecting plant growth such as soil physical properties, nutrient status, etc. However, there is some evidence that pipeline construction may improve plant growth for some period of time, particularly in Solonetzic soils.

5. RECOMMENDATIONS FOR FURTHER WORK

1. There is a general lack of consistent information for pipelines on the length of time required for elevated soil salt contents to return to an acceptable level, and the factors which influence that rate of return. An extensive study of existing pipelines of various ages across soil zones and soil textures is needed.
2. There is a need for a detailed literature review and study on seasonal salt fluctuation in disturbed soils with a potential for 3-lift procedures. Such data would help determine whether the existing criteria are consistent with the degree of seasonal salt fluctuation to be found in Alberta soils, and whether time of year of sampling could affect a decision to 3-lift a pipeline segment. This review could include an examination of the movement of salts in disturbed soil, due to single major rainfall events.

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7.1 APPENDIX 1

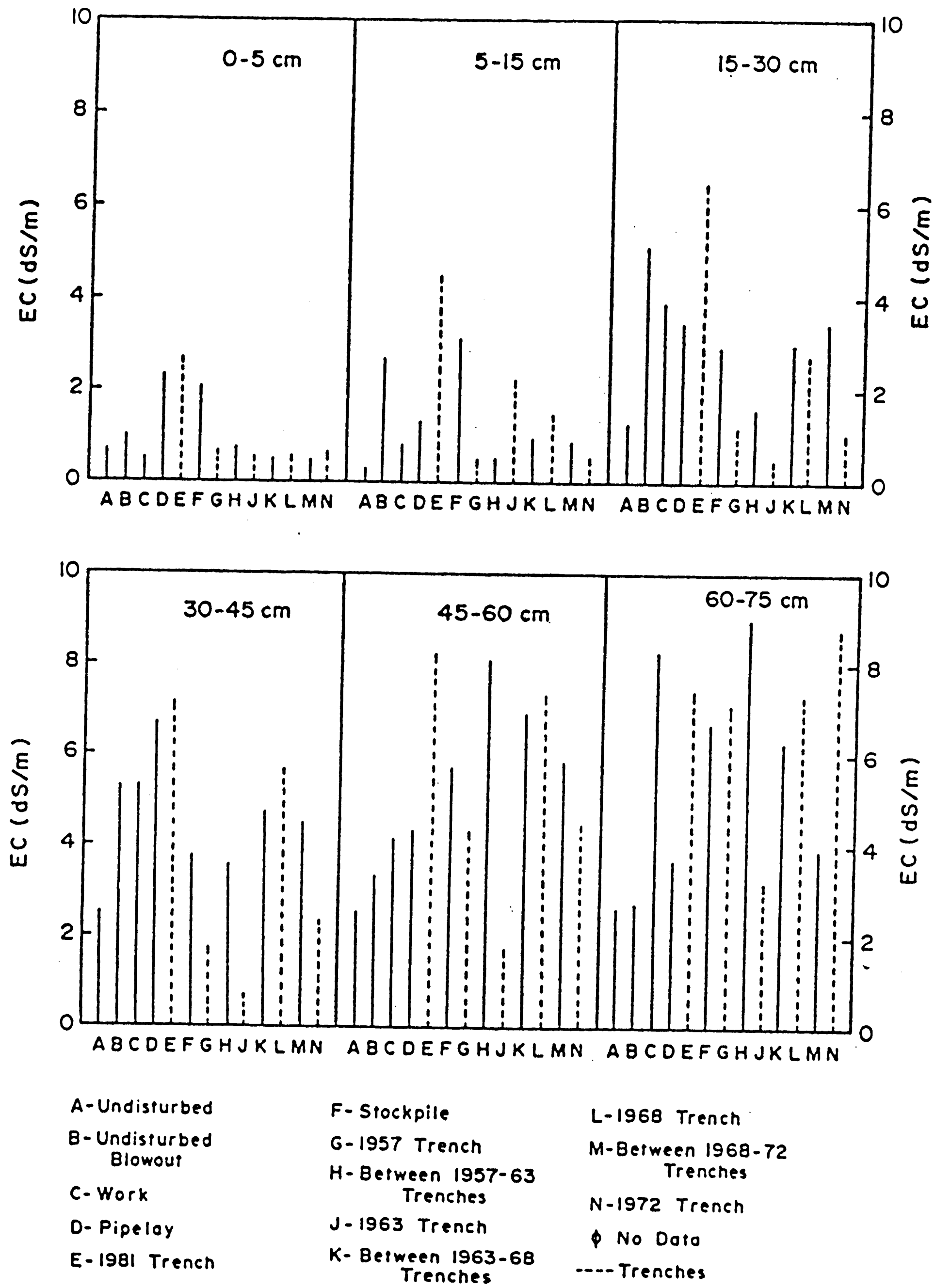

Figure 2. Profile electrical conductivity among transects, site 2 (Naeth 1985).

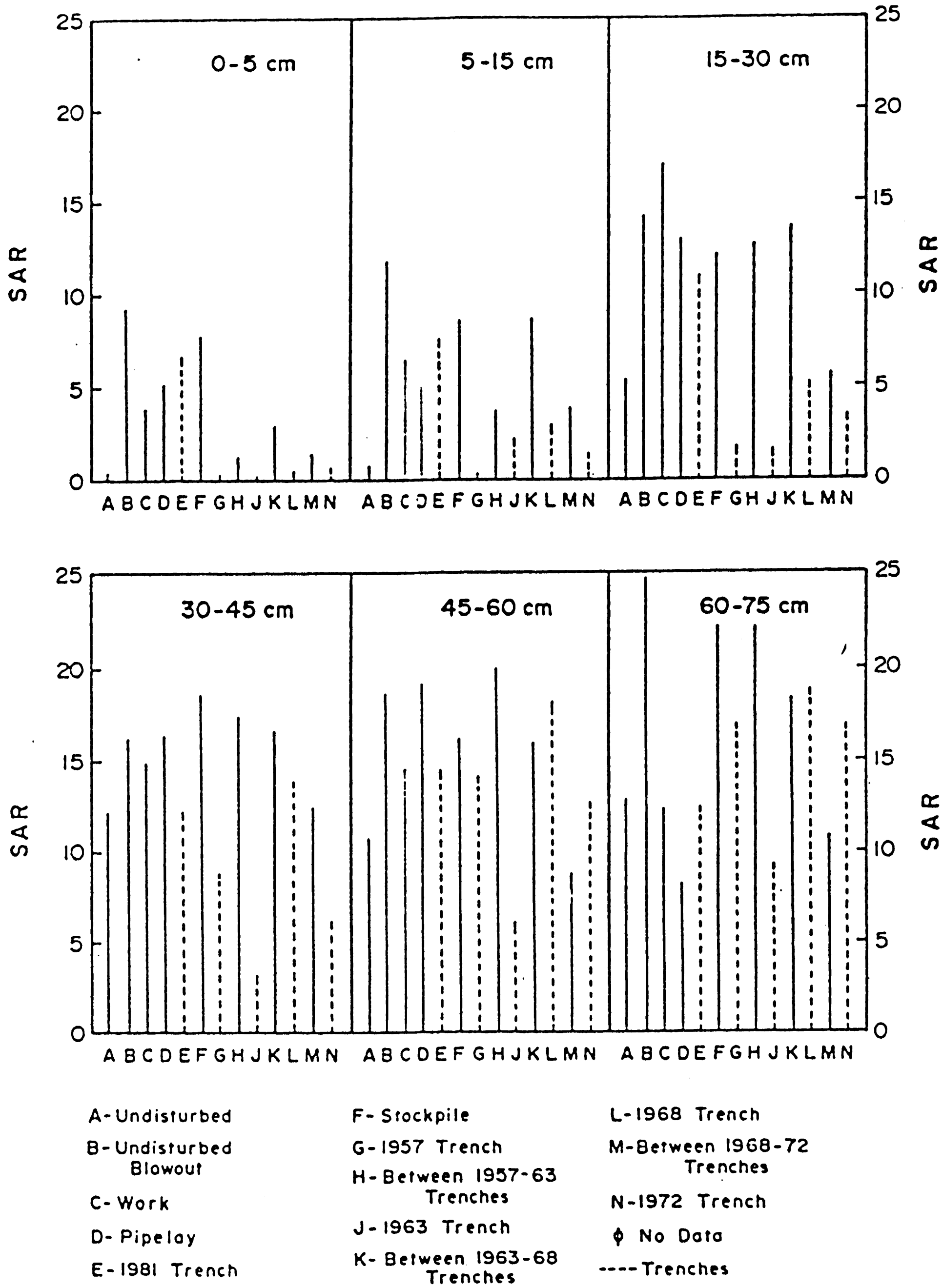

Figure 3. Profile sodium adsorption ratio among transects, site 2 (Naeth 1985).

RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; out-planting; and, species selection.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes. Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-2: Alberta's Reclamation Research Program - 1979. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,190,006 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

4. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. No longer available.**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

5. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

6. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

7. **RRTAC 81-1: The Alberta Government's Reclamation Research Program - 1980. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,455,680 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

8. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

9. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

10. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

11. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

12. **RRTAC 82-3: The Alberta Government's Reclamation Research Program - 1981. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,499,525 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

13. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials (See RRTAC 92-4).

14. **RRTAC 83-2: The Alberta Government's Reclamation Research Program - 1982. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,536,142 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

15. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

16. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

17. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

18. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

19. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

20. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report describes the expenditure of $1,529,483 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

21. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

22. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00.**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

23. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. No longer available.**

This report describes the expenditure of $1,320,516 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

24. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

25. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

26. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

27. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

28. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

29. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

30. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

31. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report describes the expenditure of $1,168,436 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

32. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

33. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

34. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. No longer available.**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

36. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. No longer available.**

This report describes the expenditure of $1,186,000 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

37. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

38. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

39. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

40. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

41. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

42. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

43. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

44. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. No longer available.**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

45. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

46. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

47. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. No longer available.**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

48. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

49. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

50. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. No longer available.**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

51. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

52. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

53. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

54. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. No longer available.**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

55. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. No longer available.**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

56. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

57. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

58. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

59. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. No longer available.**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

60. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. ISBN 0-7732-0878-X. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

61. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. ISBN 0-7732-0882-8. $10.00.**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

62. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. No longer available.**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

63. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. No longer available.**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

64. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

65. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. No longer available.**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

66. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

67. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

68. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. S.R. Moran, T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

69. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

70. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

71. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

72. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and referred journals.

73. **RRTAC 90-9: Literature Review on the Disposal of Drilling Waste Solids. Monenco Consultants Limited. 83 pp. $5.00**

This report reviews the literature on, and government and industry experience with, burial of drilling waste solids in an Alberta context. The review covers current regulations in Alberta, other provinces, various states in the US and other countries. Definitions of various types of burial are provided, as well as brief summaries of other possible disposal methods. Environmental concerns with the various options are presented as well as limited information on costs and monitoring of burial sites. The main conclusion of the work is that burial is still a viable option for some waste types but that each site and waste type must be evaluated on its own merits.

74. **RRTAC 90-10: Potential Contamination of Shallow Aquifers by Surface Mining of Coal. M.R. Trudell, S.R. Moran and T.M. Macyk. 75 pp. $5.00**

This report presents the results of a field investigation of the movement of salinized groundwater from a mined and reclaimed coal mine near Forestburg into an adjacent unmined area. The movement is considered to be an unusual occurrence resulting from a combination of a hydraulic head that is higher in the mined area than in the adjacent coal aquifer, and the presence of a thin surficial sand aquifer adjacent to the mine. The high hydraulic head results from deep ponds in the reclaimed landscape that recharge the base of the spoil.

75. **RRTAC 91-1: Reclamation Research Annual Report - 1990. Reclamation Research Technical Advisory Committee. 69 pp. No longer available.**

This annual report describes the expenditure of $499 612 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program. The report lists the 70 research reports published under the program.

76. **RRTAC 91-2: Winter Soil Evaluation and Mapping for Regulated Pipelines. A.G. Twardy. 43 pp. ISBN 0-7732-0874-7. $5.00**

Where possible, summer soil evaluations are preferred for pipelines. However, when winter soil evaluations must be done, this report lays out the constraints and requirements for obtaining the best possible information. Specific recommendations include: restricting evaluations to the time of day with the best light conditions; use of core- or auger-equipped drill-trucks; increased frequency of site inspections and soil analyses; and, hiring a well-qualified pedologist. The province's soils are divided into four classes, based on their difficulty of evaluation in winter: slight (most soils); moderate; high; and, severe (salt-affected soils in the Brown and Dark Brown Soil Zones).

77. **RRTAC 91-3: A User Guide to Pit and Quarry Reclamation in Alberta. J.E. Green, T.D. Van Egmond, C. Wylie, I. Jones, L. Knapik and L.R. Paterson. 151 pp. ISBN 0-7732-0876-3. $10.00**

Sand and gravel pits or quarries are usually reclaimed to the original land use, especially if that was better quality agricultural or forested land. However, there are times when alternative land uses are possible. This report outlines some of the alternate land uses for reclaimed sand and gravel pits or quarries, including: agriculture, forestry, wildlife habitat, fish habitat, recreation, and residential and industrial use. The report provides a general introduction to the industry and to the reclamation process, and then outlines some of the factors to consider in selecting a land use and the methods for reclamation. The report is <u>not</u> a detailed guide to reclamation; it is intended to help an operator determine if a land use would be suitable and to guide him or her to other sources of information.

78. **RRTAC 91-4: Soil Physical Properties in Reclamation. M.A. Naeth, D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 204 pp. ISBN 0-7732-0880-1. $10.00**

This report provides information from the literature and Alberta sources on a variety of soil physical properties that can be measured on reclaimed sites. Each property is explained, measurement methods, problems, level of accuracy and common soil values are presented, and methods of dealing with the property (prevention, alleviation) are discussed. The report also contains the results of a workshop held to discuss soil physical properties and the state-of-the-art in Alberta.

79. **RRTAC 92-1: Reclamation of Sterilant Affected Sites: A Review of the Issue in Alberta. M. Cotton and M.P. Sharma. 64 pp. ISBN 0-7732-0884-4. No longer available**

This report assesses the extent of sterilant use on oil and gas leases in Alberta, identifies some of the concerns related to reclamation of sterilant affected sites and the common methods for reclaiming these sites, and outlines the methods for sampling and analyzing soils from sterilant affected sites. The report also provides an outline of a research program to address issues raised by government and industry staff.

80. **RRTAC 92-2: Reclamation Research Annual Report - 1991. Reclamation Research Technical Advisory Committee. 55 pp. ISBN 0-7732-0888-7. No longer available.**

This report describes the expenditure of $485,065 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the five program areas, and describes the projects funded under each program. It also lists the 75 research reports that have been published to date.

81. **RRTAC 92-3: Proceedings of the Industry/Government Pipeline Reclamation Success Measurement Workshop. R.J. Mahnic and J.A. Toogood. 62 pp. ISBN 0-7732-0886-0. $5.00.**

This report presents the results of a workshop to identify the soil and vegetation parameters that should be used to assess reclamation success on pipelines in Alberta. Six soil parameters (topsoil admixing; topsoil replacement thickness; compaction; soil loss by erosion; texture; and salinity) and six vegetation parameters (plant density; species composition; ground cover; vigour; weeds/undesirable species; and rooting characteristics) were selected as most important. Working groups discussed these parameters and presented suggested methods for assessing them in the field.

82. **RRTAC 92-4: Oil Sands Soil Reconstruction Project Five Year Summary. HBT AGRA Limited. 109 pp. ISBN 0-7732-0875-5. $10.00**

This report documents a five year study of the effects of clay and peat amendments to oil sand tailings sand on survival and growth of trees and shrubs. Ten species (jack pine, white spruce, serviceberry, silverberry, buffaloberry, pin cherry, prickly/woods rose, Northwest poplar, green alder, and Bebb willow) were planted into tailings sand amended with three levels of peat and three levels of clay. The treatments were incorporated to a depth of 20 cm or 40 cm. Data are provided on plant survival and growth, root size and distribution, disease and small mammal damage, herbaceous cover, soil moisture, soil chemistry, and bulk density.

83. **RRTAC 92-5: A Computer Program to Simulate Groundwater Flow and Contaminant Transport in the Vicinity of Active and Reclaimed Strip Mines: A User's Guide. A.S. Crowe and F.W. Schwartz, SIMCO Groundwater Research Ltd. 104 pp. plus appendix. ISBN 0-7732-0877-1. NOTE: This report is only available from the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7 as ARC Information Series 119. The cost is $20.00 and the cheque must be made out to the Alberta Research Council.**

The manual describes a computer program that was developed to study the influence of coal strip mining on groundwater flow systems and to simulate the transport of generated contaminants, both spatially and in time, in the vicinity of a mine. All three phases of a strip mine can be simulated: the pre-mining regional groundwater flow system; the mining and reclamation phase; and, the post-mining water level readjustment phase. The model is sufficiently general to enable the user to specify virtually any type of geological conditions, mining scenario, and boundary conditions.

84. **RRTAC 92-6: Alberta Drilling Waste Sump Chemistry Study. Volume I: Report (Volume II: Appendices is only available through the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7. The cost is $15.00 and the cheque must be made out to the Alberta Research Council.). T.M. Macyk, S.A. Abboud and F.I. Nikiforuk, Alberta Research Council. 217 pp. ISBN 0-7732-0879-8. $10.00.**

This study synthesizes the data from sampling and analysis of the solids and liquids found in 128 drilling waste sumps across Alberta. Drilling waste types sampled included: 72 freshwater gel, 19 invert, 27 KCl, 2 NaCl, and 8 others. Data and statistics are tabulated by waste type, depth of the drill hole, and ERCB administrative region for both the solids and the liquids. Using preliminary loading limits developed by the government/industry Drilling Waste Review Committee, the report presents information on the volume and depth of waste that could be landspread, and the area required for landspreading. The oil and gas industry provided approximately $585,000 for the sampling and analysis phase of this study.

85. **RRTAC 93-1: Reclamation of Native Grasslands in Alberta: A Review of the Literature. D.S. Kerr, L.J. Morrison and K.E. Wilkinson, Environmental Management Associates. 205 pp. plus appendices. ISBN 0-7732-0881-X. $10.00.**

A review of the literature on native grassland reclamation was conducted to summarize the current state of knowledge on reclamation and restoration efforts within Alberta. The review is comprehensive, including an overview of the regulations and guidelines governing land use on native prairie; a description of the dominant grassland ecoregions in Alberta; a review of the common disturbance types, extent and biophysical effects of disturbance on native prairie within Alberta; a description of the factors which influence the degree of disturbance and reclamation; and examples of both natural and enhanced recovery of disturbed sites through the examination of selected case studies.

86. **RRTAC 93-2: Reclamation Research Annual Report - 1992. Reclamation Research Technical Advisory Committee. 56 pp. ISBN 0-7732-0883-6. $5.00.**

This report describes the expenditure of $474,705 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and the research strategies of the five programs, and describes the projects funded under each program. It also lists the 85 research reports that have been published to date.

87. **RRTAC 93-3: Catalogue of Technologies for Reducing the Environmental Impact of Fine Tailings from Oil Sand Processing. B.J. Fuhr, Alberta Research Council, D.E. Rose, Dereng Enterprises Ltd., and D. Taplin, Komex International Ltd. 63 pp. ISBN 0-7732-0885-2. $5.00.**

A catalogue containing 22 technologies for reducing the environmental impact of fine tailings derived from oil sands has been assembled. The report consists of an introduction to oil sand processing and fine tailings generation, a simple spreadsheet for comparing the technologies, and a process summary for each technology. The technologies were not evaluated for effectiveness. Rather, a detailed set of questions was prepared that highlights the environmentally-related information a proponent should have. These questions will help to form a basis for comparisons among the technologies.

88. **RRTAC 93-4: Organic Materials as Soil Amendments in Reclamation: A Review of the Literature. Land Resources Network Ltd. 228 pp. ISBN 0-7732-0887-9. $10.00**

A review of the literature was conducted to examine the effect of various organic materials when used as amendments to disturbed soil. Organic amendments reviewed included animal manures, crop residues, peat, wood wastes, sewage sludge, municipal yard waste, humates, vermicomposts, and spent mushroom composts. Their effects on soil chemistry, physical properties, and biology were examined. Application methods, costs, longevity of effects, and use in reclamation were also reviewed. Benefits and drawbacks of each were discussed.

89. **RRTAC 93-5: Drilling Waste Disposal. T.M. Macyk and S.A. Abboud, Alberta Research Council. 125 pp. ISBN 0-7732-0889-5. $10.00**

An overall perspective and description of the steps involved in the management and land-based disposal of drilling wastes in Alberta. A computer program, available from the Alberta Research Council, has been written to support the data management required for proper disposal. A field manual is in preparation. These three information sources provide technical support for the Energy Resources Conservation Board's Guide G-50: Drilling Waste Management.

90. **RRTAC 93-6: Mapping and Characterization of Cutover Peatlands for Reclamation Planning. L.W. Turchenek, Alberta Research Council, W.S. Tedder, Alberta Agriculture, Food and Rural Development, and R. Krzanowski, Alberta Research Council. 100 pp. ISBN 0-7732-6038-2. $5.00**

The report presents a methodology for cost-effective soil survey and sampling of cutover peatlands. It also presents baseline chemical information and data interpretation for peat materials from a cutover peatland site. The report provides background information on classifying and describing peatlands. This information can be used to develop reclamation plans.

91. **RRTAC 93-7: Soil Series Information for Reclamation Planning in Alberta. Pedocan Land Evaluation Ltd. Various pagings. ISBN 0-7732-6041-2. $10.00**

This manual has been published to provide conservation and reclamation planners with information and guidelines to help understand and use soil inventory data. The soil series in the manual correspond to those in the Generation 2 Alberta Soil Names File. Part 1 of the manual describes the terminology used in soil surveys and presents the assumptions and conventions upon which the interpretations for each soil series are based. Part 2 presents typical data and interpretations for each soil series.

92. **RRTAC 93-8: Oils Sands Sludge Dewatering by Freeze-Thaw and Evapotranspiration. R.L. Johnson, P. Bork. W. H. James and L. Koverny, Alberta Environmental Centre. 247 pp. ISBN 0-7732-6042-0. $10.00**

This report presents data from a series of laboratory and field experiments designed to evaluate the removal of water from oil sands sludge. A number of plant species were evaluated and two, reed canary grass and western dock, were found to remove a significant amount of water through evapotranspiration. Freeze-thaw cycles were also found to remove water from both sand-sludge mixtures and pure sludge. A combination of freeze-thaw and biological dewatering using plants was found to increase solids content from 30% to 80%. At 80% solids the sludge had a shear strength of 120 kPa and could support machine traffic. These studies prompted further field work.

93. **RRTAC 93-9: Native Legumes for Reclamation in Alberta. A. Smreciu, Wild Rose Consulting Inc. 94 pp. ISBN 0-7732-0643-9. $5.00**

Seeds from *Astragalus* (milkvetches), *Hedysarum* (sweetbrooms), *Lupinus* (lupins), and *Oxytropis* (locoweeds) were collected from the mountains and foothills region of Alberta, from Waterton Lakes National Park to Grande Cache. The species were tested for germination and seedlings were established and evaluated for three growing seasons in Vegreville. The species were evaluated based on survival, growth and development, and yield. *Astragalus alpinus* was selected as the most promising species. *Oxytropis monticola* and *Oxytropis splendens* were also recommended.

94. **RRTAC 93-10: Proceedings of the Alberta Wellsite Reclamation Criterial Workshop. R.J. Mahnic, Communiplan Inc., L.J. Knapik and T.R. Bossenberry, Pedocan Land Evaluation Ltd., and G.C. Mott, G.C. Mott Associates. Various Pagings. ISBN 0-7732-0644-7. $10.00**

This report summarizes government, industry and public comments received before and during a two-day workshop held to discuss the *Reclamation Criteria for Wellsites and Associated Facilities*. The information in the report was used to revise the Criteria for use from 1994 onward.