REPORT #
RRTAC 92-4

Oil Sands Soil Reconstruction Project Five Year Summary

by

HBT AGRA Limited

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The Oil Sands Reclamation Research Program
ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
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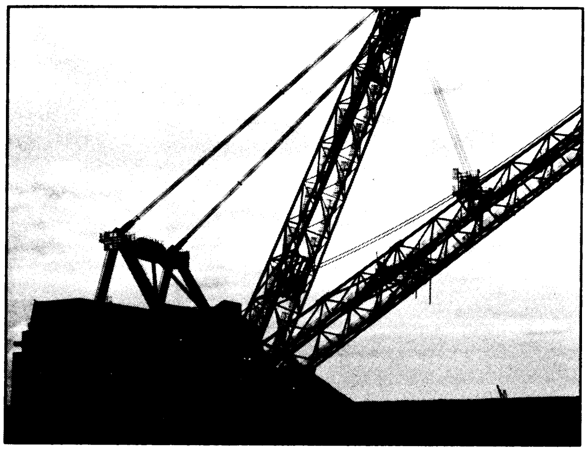
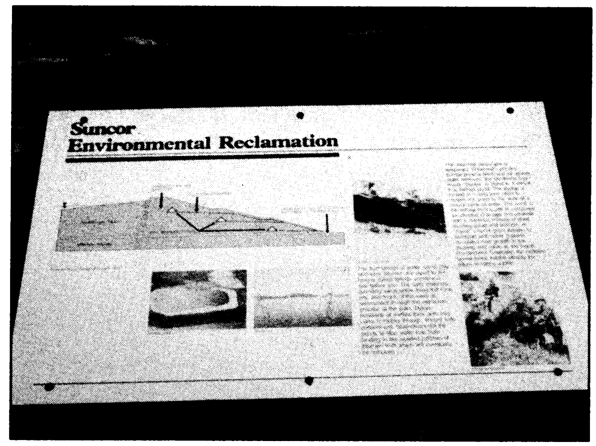
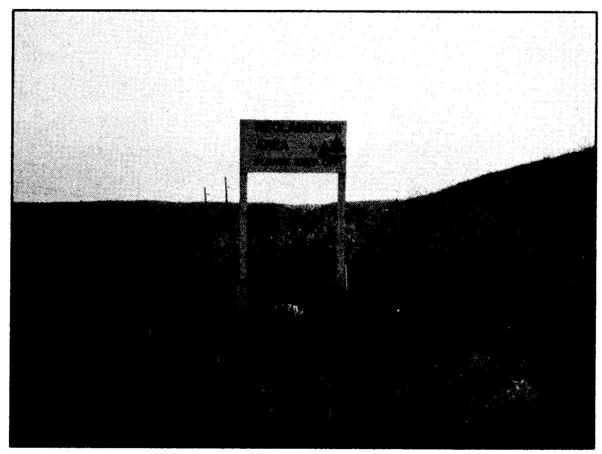
Oil Sands Reclamation Research Program







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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 Development 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

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EXECUTIVE SUMMARY

In fall 1983, study plots were established on a near level tailings sand pad on the Syncrude Canada Ltd. oil sands mine site, north of Fort McMurray, Alberta. The plots consisted of soil reconstructed by applying and mixing various quantities of peat and clayey overburden at two depths (20 and 40 cm). In all, 18 treatments were established, consisting of three application rates each of peat and overburden, to form nine reconstructed soil formulations to be tested at each depth.

The objectives of the study were to determine which mixtures would support establishment of an initial vegetation cover, as well as evolve over time to support a maintenance-free forest cover of a desired level of productivity. To test these mixtures, ten species of trees and shrubs were planted in fall 1984 to act as indicators of soil capability.

The original component materials and the various mixtures were analyzed for a variety of soil physical and chemical properties. The principal difference in the reconstructed soil among the three application rates of peat was organic carbon content, averaging 1.3, 2.4, and 4.1 percent, respectively. The three overburden applications resulted in reconstructed soils differing mainly in texture, especially clay content which averaged 3, 9, and 13 percent, respectively. Increasing peat application led to increased quantities of total nitrogen and sulphur, while overburden application increased total phosphorus and potassium. The most significant changes in plant available forms of these nutrients was an increase in nitrogen with peat application.

Moisture retention of the soil mixtures, as measured in the laboratory, increased with addition of peat and overburden to approximately the same extent. However, field measurements showed an increase with peat addition but not overburden. Consequently, there was less plant available moisture in treatments with increasing overburden. The difference between laboratory and field results is attributed to the ineffectiveness of the large scale equipment used in the field to thoroughly mix the clayey overburden. There was no difference in the amount of moisture within the upper 105 cm profile for any treatments, but the treatments with the thicker (40 cm)

reconstructed soil had more of this moisture near the surface than did the 20 cm treatments.

An initial ground cover established more rapidly with increasing application of peat and overburden, and on the 40 cm thick layer as opposed to the 20 cm. Invading agronomic species, seeded in the surrounding region, contributed most of the cover.

Woody plant survival after five years in the field was relatively high at over 90 percent for half of the planted species. Most of the species had slightly better survival with peat application but lower survival with overburden. Damage due to disease, insects or small mammals had only a very minor impact on survival.

Top growth of most species was lower with increasing overburden application while the two conifers tested (jack pine and white spruce) grew better with increasing peat. The 40 cm treatments also had slightly better growth than the 20 cm treatments.

Root growth tended to be contained within the upper 20 cm layer irrespective of soil mixing depth but most plants on the thinner (20 cm) treatments tended to have slightly larger root systems, opposite to the trend noted for top growth.

The best overall mixture based on seedling performance and initial ground cover established was the high peat, low overburden application at 40 cm thickness. However, there are no comparable data on seedling growth from natural soils in the region to determine which test mixtures might provide equal productivity.

The use of a heavy clay overburden in reclamation is not recommended unless a method is found to thoroughly blend this material on an operational scale.

ABSTRACT

Treatment plots were established on the Syncrude Canada Ltd. oil sands mine site to test the effect of a variety of mixtures of peat, mineral overburden, and tailings sand on establishment of an initial vegetation cover and productivity of planted trees and shrubs. Treatments consisted of nine combinations of peat and overburden, each mixed to depths of 20 and 40 cm. Application of peat provided the greatest benefit in terms of soil physical and chemical properties, especially plant available moisture. Overburden application increased nutrient status but had a detrimental effect on plant available moisture. Increased thickness of the reconstructed layer retained more moisture near the surface. An initial ground cover established more quickly with increasing peat, overburden, and thickness. Seedling survival after five years was higher for most species with increasing peat but lower with overburden application. Conifers grew better with increasing peat while most species had poorer growth with increasing overburden. Growth was also slightly better on the thicker reconstructed soils.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 BACKGROUND

Open pit oil sands mines such as the Suncor Inc. (Suncor) and Syncrude Canada Limited (Syncrude) mines north of Fort McMurray, Alberta result in the disturbance and subsequent need for reclamation of thousands of hectares of land. The long-term reclamation goal of these operations is the reestablishment of vegetation communities that are self-sustaining and compatible with the surrounding undisturbed terrain on at least 70 percent of the reclaimed area, while the remaining area (up to 30 percent) can be occupied by waterbodies. Of the 70 percent land component, 60 percent must be returned to commercial forest and the remaining 10 percent for other land uses. An important step in meeting this goal is the development of a suitable soil on the residual tailings sand after oil extraction.

The Oil Sands Soil Reconstruction Project represents Phase II of a study to determine the design requirements of a suitable soil constructed of tailings sand, peat and mineral overburden. Phase I of the study involved a literature review conducted by Monenco Consultants Ltd. (1983). As part of the preliminary soil reconstruction objectives of the Phase I study, design criteria were developed for the establishment of jack pine and mixed wood vegetation communities on reclaimed tailings sand. The Phase II study was essentially a field trial of the recommended soil reconstruction criteria in which three application rates of peat and mineral overburden were mixed to form nine reconstructed soil formulations and two mixing depths (i.e., 18 treatments).

Hardy Associates (1978) Ltd. (now HBT AGRA Limited) was commissioned to undertake the study beginning with plot construction in the fall of 1983 and with subsequent annual monitoring through 1989.

1.2 SCOPE

This report describes plot construction methods and monitoring results from the fall of 1983 to 1989. Included are monitoring results from five consecutive years of data collection on:

1. soil chemical properties;
2. soil moisture;
3. herbaceous ground cover; and
4. tree and shrub survival and growth.

Emphasis is placed on differences in soil and vegetation properties among treatments based on data collected during the last year of the study (1989). Other data collected intermittently and summarized in this report include:

1. tree and shrub rooting distribution;
2. moisture retention properties of the original amendment materials and mixtures;
3. selected soil chemical and physical properties of the original amendment materials;
4. incidence of disease and small mammal damage;
5. rhizome development in selected species; and
6. groundwater elevations.

1.3 OBJECTIVE

The objective of the study was to identify methods of constructing soils from tailings sand, peat and clayey materials which will:

1. support desired initial vegetation cover; and
2. evolve over time and in response to the forces of pedogenesis in the oil sands region into a soil capable of supporting a maintenance-free forest of the desired level of productivity.

2. STUDY AREA

The Suncor and Syncrude oil sands mine operations are adjacent to each other, approximately 50 km north of Fort McMurray, Alberta (Figure 1). Prior to development, the leases supported a boreal mixed wood vegetation type (Rowe 1972) consisting of white spruce (*Picea glauca*), aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), balsam fir (*Abies balsamea*), and white birch (*Betula papyrifera*) as the major upland species. Jack pine (*Pinus banksiana*) occurred locally on dry sandy sites and often formed a mixture with black spruce (*Picea laricina*) on level hill tops. Black spruce and larch (*Larix occidentalis*) muskeg occurred in depressions and poorly drained flats.

The dominant soils included Luvisols, Organics and Gleysols (Crown and Twardy 1970). The Luvisols occurred mainly on the well to moderately well drained upland sites with parent materials of glacial till, glacio-lacustrine or glacial outwash. Organic and Gleysolic soils occurred on the poorly drained sites and typically contained thick (50 to 300 cm or more) layers of sphagnum moss at the surface.

The area has a subarctic continental climate characterized by short, cool summers and long, cold winters. Long-term climate data are available from Fort McMurray (Environment Canada 1982a,b). Mean annual temperature is -0.2°C ranging from 16.4°C in July to -21.8°C in January. Annual precipitation averages 471.9 mm, most of which (252.4 mm) falls as rain during the growing season (May to August). The average frost-free period is 67 days (Boughner 1974).

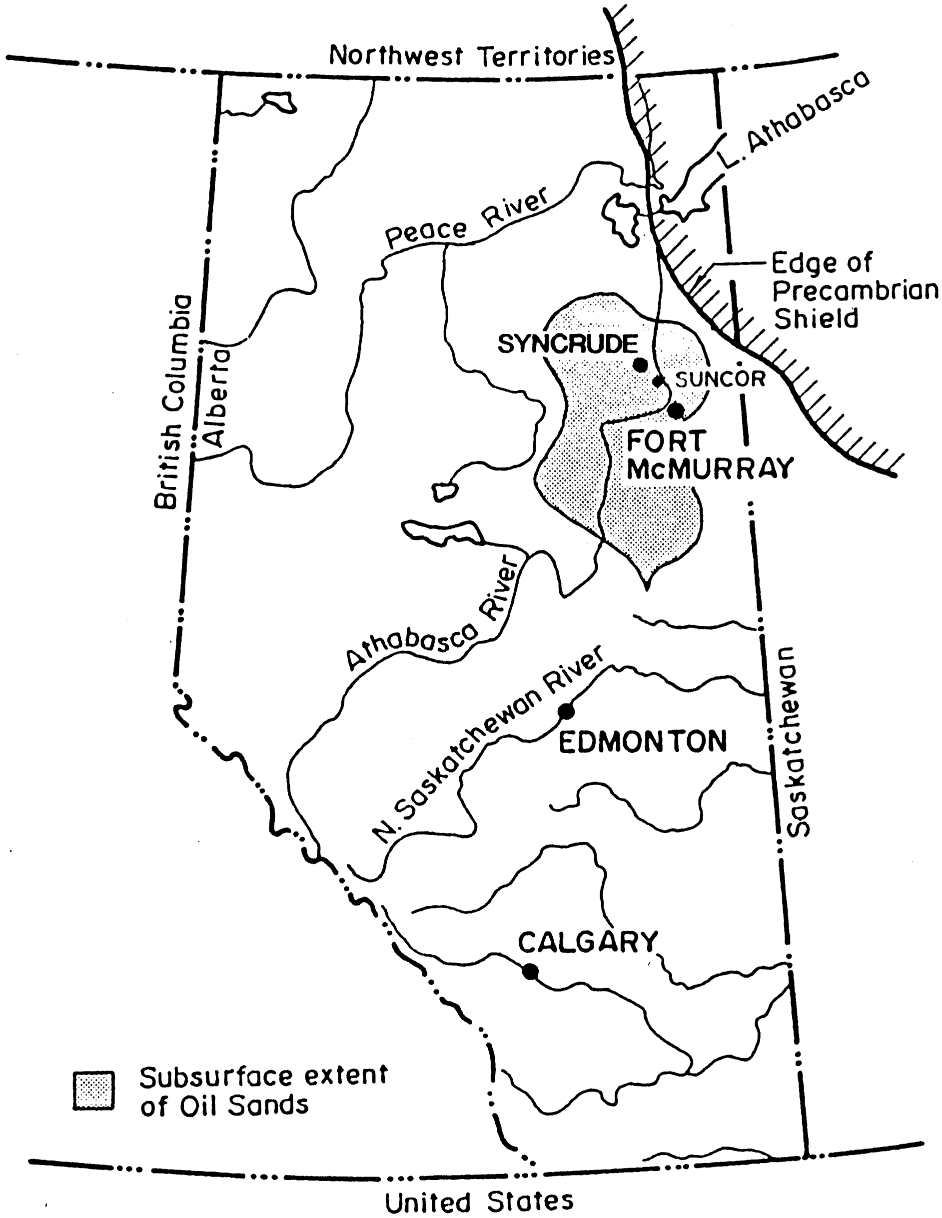


Figure 1. Location of the Study Area.

3. METHODS

3.1 PLOT ESTABLISHMENT

The tailings sand pad was constructed adjacent to Syncrude's tailings pond using the standard cell construction methods. The pad was built on top of previously cleared mixedwood forest terrain and ranged from an estimated 3 m to 5 m in thickness. The cleared land bordered the pad to the west and south (Figure 2). A ditch separated the pad from the tailings pond dyke along the east side, while the north was bordered by a mine road and adjacent ditch.

3.1.1 Experimental Design

The study was designed as a 3 by 3 by 2 factorial experiment configured in a randomized complete block design. The original design criteria were based on various application rates of peat and clay overburden that would produce all nine combinations of three levels of organic carbon content (1, 3, and 5 percent by weight) and three levels of clay content (0, 12, and 24 percent) in the final reconstructed soil. Each of these "reconstructed soil types" would be tested at two mixing thicknesses, 20 and 40 cm, for a total of 18 treatments. Each treatment was replicated three times giving a total of 54 plots. To simplify terminology, throughout this report the amendment treatments will be referred to as Low, Medium, and High application rates of peat or overburden. The plot arrangement is illustrated in Figure 3.

Selection of treatments was based on recommendations by Monenco Consultants Limited (1983). Their suggested minimal requirements for jack pine and mixedwood starter soils were as follows:

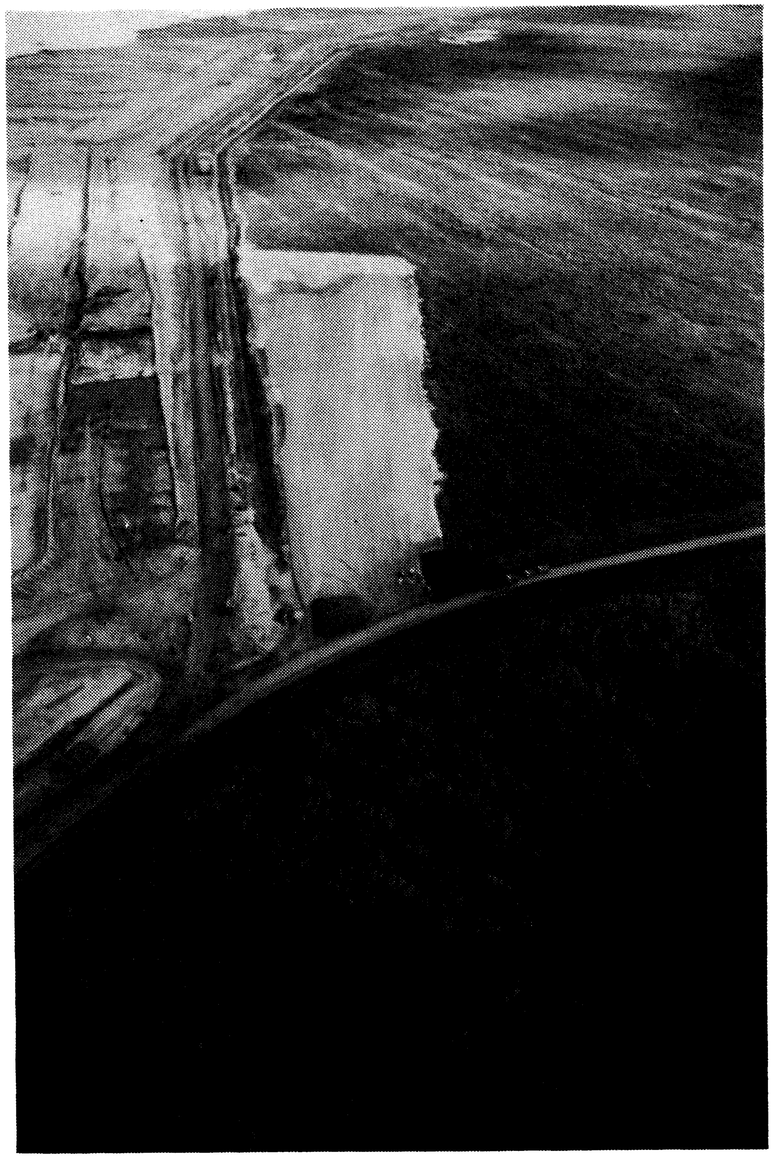


Figure 2. Aerial view of the tailings sand pad immediately prior to application of amendments.

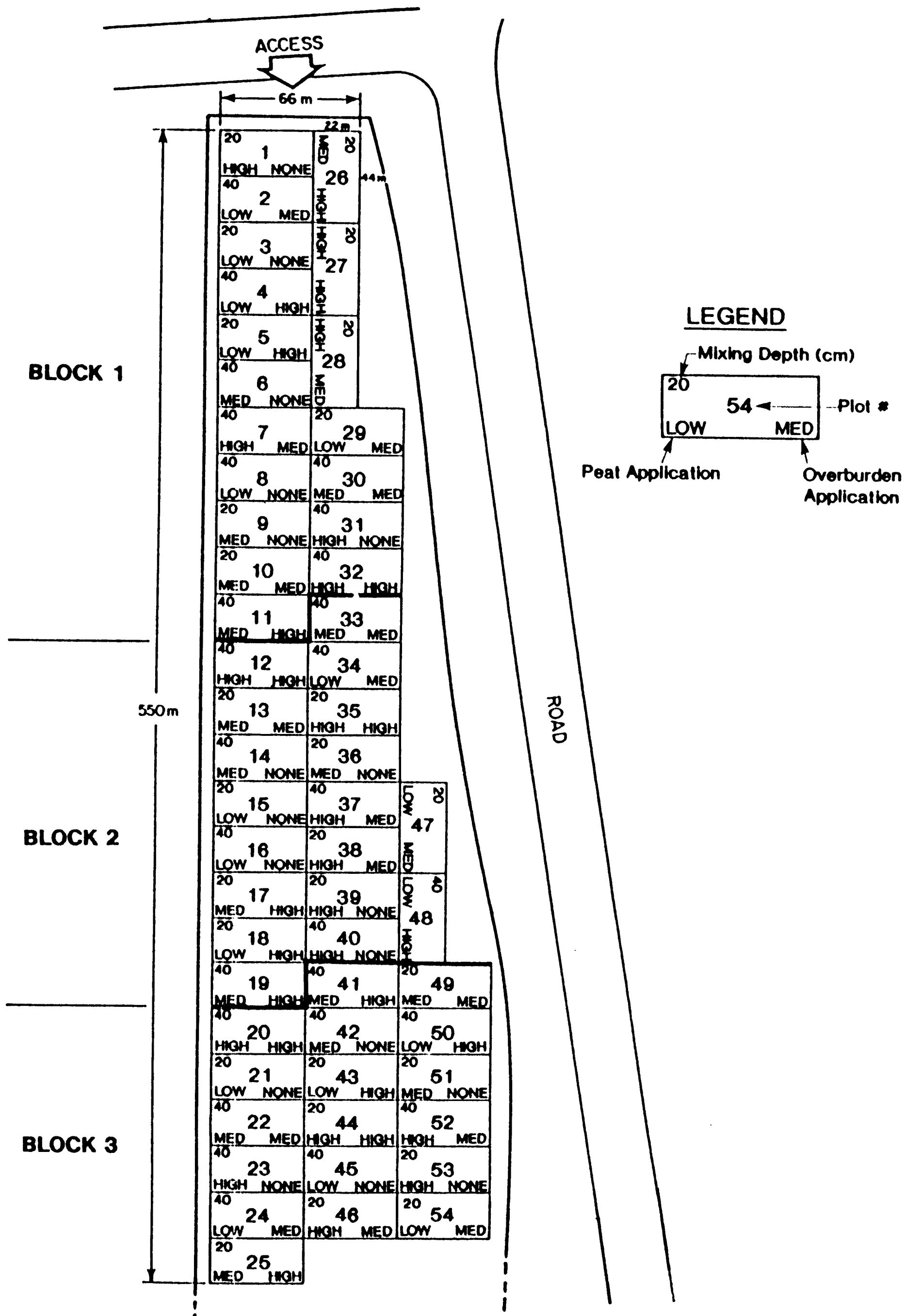


Figure 3. Plot Arrangement.

Recommended Minimal Physical and Chemical Characteristics of Soils

Soil Property	jack pine	Mixedwood Horizon 1	Mixedwood Horizon 2
Thickness (cm)	15	15	35
Silt and Clay (%)	25	30	15
Organic Matter (%)	2.5	6	2

3.1.2 Plot Configuration

A typical plot configuration is shown in Figure 4. Individual plots measured 44 m by 22 m within which, 10 "species subplots" were partitioned, each measuring 10 m by 8 m. This allowed for buffer strips of 2 m to 4 m between plots. Species subplots were randomly assigned within each main plot. Forty individuals of each species were planted in four rows with 2 m spacing between rows and 1 m spacing between plants within a row. Planting is described in more detail in Section 3.5.

3.1.3 Amendment Calculation

Quantities of peat and mineral overburden to be applied to the plots and mixed into the sand were calculated based on the following formulae and assumptions.

$$Cr = \frac{Tp \bullet Bp \bullet Cp \bullet 100}{(Tp \bullet Bp) + (Tt \bullet Bt) + Bs \bullet (Tr - Tp - Tt)}$$

$$Tp = \frac{Cr \bullet ((Tt \bullet Bt) + (Tr \bullet Bs) - (Tt \bullet Bs))}{(Bp \bullet Cp \bullet 100) + (Cr \bullet Bs) - (Cr \bullet Bp)}$$

$$Mr = \frac{Tt \bullet Bt \bullet Mt \bullet 100}{(Tp \bullet Bp) + (Tt \bullet Bt) + Bs \bullet (Tr - Tp - Tt)}$$

$$Tt = \frac{Mr \bullet ((Tp \bullet Bp) + (Tr \bullet Bs) - (Tp \bullet Bs))}{(Bt \bullet Mt \bullet 100) + (Mr \bullet Bs) - (Mr \bullet Bt)}$$

Where:

Cr - Organic Carbon percent of reconstructed soil (1, 3 or 5 percent)

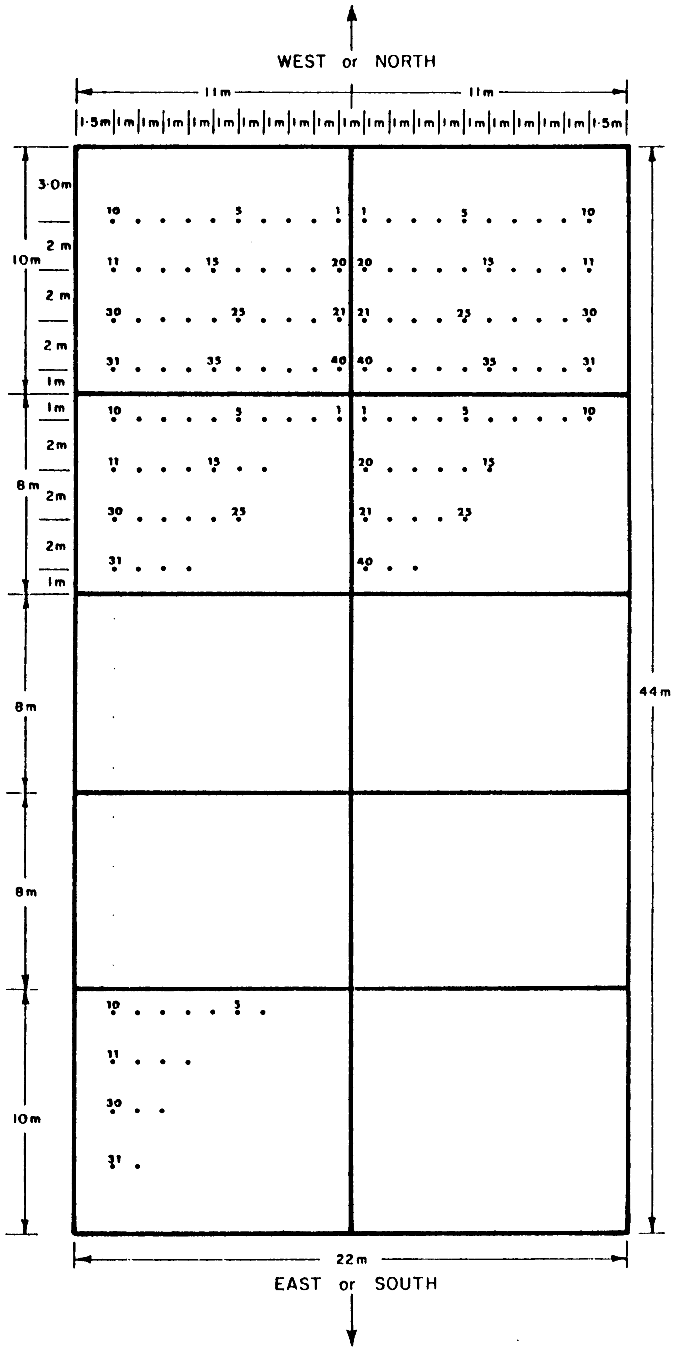


Figure 4. Typical Plot Configuration.

Cp - Organic Carbon percent of peat amendment (assumed 40 percent)

Mr - Clay percent of reconstructed soil (0, 12 or 24 percent)

Mt - Clay percent of mineral overburden (till) amendment (measured 40 percent)

Tp - Thickness of peat amendment (cm)

Tt - Thickness of mineral overburden amendment (cm)

Tr - Thickness of reconstructed soil (20 or 40 cm)

Bp - Bulk density of peat amendment (assumed 0.1 g/cm^3)

Bt - Bulk density of mineral overburden amendment (assumed 1.5 g/cm^3)

Bs - Bulk density of tailings sand (assumed 1.5 g/cm^3)

Two important assumptions of these equations are that the peat is the only source of organic carbon and the mineral overburden is the only source of clay. Furthermore, the bulk densities of the materials (especially peat and mineral overburden) are assumed to be the same after spreading as they are in a stockpile (i.e., no compaction takes place during spreading). This latter assumption was especially important because the thicknesses of the amendment materials were converted into volumes so that during construction of the plots the number of truckloads (of known volume) could be counted as an estimate of the proper quantities to be added to each plot. The resulting volumes calculated for each treatment are given in Table 1.

3.1.4 Plot Construction

Plot construction took place during September and October of 1983. Activities included hauling, spreading, and mixing of the amendment materials along with incorporation of a rock phosphate fertilizer at the time of mixing.

3.1.4.1 Hauling and spreading. Peat was hauled from a stockpile (NT-2) southeast of the Syncrude plant site, while the mineral overburden was obtained from J-pit, immediately northwest of the tailings pond. The

Table 1. Quantities of amendment material applied for each treatment.

Reconstructed Soil Horizon			Thickness of Amendment Layer (cm)		Volume of Amendment Per Plot[a] (m^3)	
Thickness (cm)	Organic Carbon (%)	Clay (%)	Peat	Mineral Overburden	Peat	Mineral Overburden
20	1	0	5.6	0.0	54.2	0.0
		12	5.6	4.4	54.2	43.0
		24	5.6	8.9	54.2	86.0
	3	0	11.0	0.0	106.5	0.0
		12	11.0	2.9	106.5	28.3
		24	11.0	5.8	106.5	56.5
	5	0	13.6	0.0	131.6	0.0
		12	13.6	2.2	131.6	21.1
		24	13.6	4.4	131.6	42.2
40	1	0	11.1	0.0	107.5	0.0
		12	11.1	8.9	107.5	86.0
		24	11.1	17.8	107.5	172.0
	3	0	22.0	0.0	213.0	0.0
		12	22.0	5.8	213.0	56.5
		24	22.0	11.7	213.0	113.1
	5	0	27.3	0.0	264.0	0.0
		12	27.3	4.4	264.0	42.2
		24	27.3	8.7	264.0	84.4

[a] Based on a treated area per plot of 22 m by 44 m.

Sample Calculation for 20 cm thickness, 3 percent organic C, 12 percent clay:

First solve for peat thickness:

$$Tp = \frac{3 \bullet ((Tt \bullet 1.5) + (20 \bullet 1.5) - (Tt \bullet 1.5))}{(0.1 \bullet 0.40 \bullet 100) + (3 \bullet 1.5) - (3 \bullet 0.1)} = \frac{90}{8.2} = 11.0$$

Then solve for mineral overburden thickness:

$$Tt = \frac{12 \bullet ((11 \bullet 0.1) + (20 \bullet 1.5) - (11 \bullet 1.5))}{(1.5 \bullet 0.40 \bullet 100) + (1.5 \bullet 12) - (1.5 \bullet 12)} = \frac{175.2}{60} = 2.9$$

overburden source chosen for the study was a near-surface, glacial lacustrine deposit (locally known as pink clay). Both peat and overburden materials were excavated with a hoe (Cat 235), loaded into off-highway trucks (Cat 777, 773B and 769C), and temporarily stockpiled on the north end of the pad prior to spreading.

Mineral overburden was extracted from the stockpile and spread on the plots in strips using an elevating scraper (Cat 613B). The spread material was left to dry for two days and then spread as evenly as possible with a small grader (Cat 12C).

Peat was hauled to the plots using the smaller model (Cat 773B and 769C) of the heavy-haulers, and spread using a wide-pad Cat D6 dozer. Boulders greater than 30 cm in diameter were moved to the edge of the plot using a Bobcat.

3.1.4.2 Application of rock phosphate fertilizer. After peat and overburden spreading, rock phosphate (0-43-0;N-P-K) fertilizer was hand-broadcast at a rate of 112 kg/ha over the plots prior to mixing.

3.1.4.3 Material mixing. The peat, overburden, and rock phosphate fertilizer were incorporated into the sand using a Madge Rotoclear landbreaker fitted with a specially designed rotor capable of mixing to a depth of 40 cm. The Rotoclear was pulled with a wide pad D6 dozer (Figure 5).

3.1.4.4 Plot reconstruction. Following baseline sampling and analyses of the mixed plots, a decision was made to add an extra volume of peat to selected treatment plots. The rationale for this decision is described in Section 4.2. Reconstruction took place in June, 1984. Selected plots (treatments targeted as 5 percent organic C content and 20 cm mixing depth) were first compacted using a CAT 815 duckfoot packer. Additional peat was spread and remixed using the same methods as for the original plot construction.

Figure 5. Mixing of amendments with the Rotoclear machine.

3.1.5 Seeding and Fertilizing

After all materials handling activities had been completed, plots were fertilized with a tractor mounted broadcaster using a 1:1 blend of 32-0-0-26 (N-P-K-S) and 0-0-62 fertilizer at a rate of 224 kg/ha. Buffer strips between plots as well as a 3 m strip around the perimeter were hand seeded to an annual barley at a rate of 40 kg/ha. Apart from the rock phosphate fertilizer incorporated during mixing, this was the only seeding and fertilizing that took place on the pad surface during the entire study.

3.1.6 Tree and Shrub Planting

Ten species of trees and shrubs were selected to act as indicators of potential productivity on the reconstructed soils. In general, species selected (Table 2) were those native to the area and with proven success in previous reclamation at Syncrude and Suncor.

Seedlings were local provenance stock produced in Hillson (160 cm^3) rootrainers except for willow which were produced in Tinus (500 cm^3) rootrainers. Willow and poplar were produced from cuttings while the rest were grown from seed. All were one year old stock at the time of planting.

Nine of the ten species of trees and shrubs were planted in September, 1984 while the tenth species (willow) was planted the following spring. As well, due to a limited number of available stock, only 35 individuals of willow were planted per plot instead of 40.

After overwintering from 1984 to June, 1985 some replacement planting was undertaken where residual stock was available. All dead poplar were replaced as well as all dead seedlings of serviceberry, silverberry, and pin cherry within plots with 80 percent or less survival (i.e., 8 or more dead individuals).

3.1.7 Installation of Neutron Probe Access Tubes

Immediately following planting, two access tubes were installed per plot so that soil moisture could be monitored using a neutron probe. Tubes were placed in the pine and poplar subplots at a randomly selected location between two adjacent seedlings within a row. Tubes were 1.5 m long (5.08 cm

Table 2. List of species planted.

Scientific Name	Common Name	N_2-Fixing
Pinus banksiana	Jack Pine	No
Picea glauca	White Spruce	No
Amelanchier alnifolia	Serviceberry	No
Elaeagnus commutata	Silverberry	Yes
Shepherdia canadensis	Buffaloberry	Yes
Prunus pensylvanica	Pin Cherry	No
Rosa acicularis/woodsii	Prickly/Woods Rose	No
Populus spp.	Northwest Poplar	No
Alnus crispa	Green Alder	Yes
Salix bebbiana	Bebb Willow	No

diameter), Class 150, thin-walled seamless aluminum installed to a depth of 1.2 m. Solid rubber stoppers were used to seal each end.

3.1.8 Fence Installation

A 2 m high Watchman fence was installed around the site in June, 1985 to exclude large mammals.

3.2 MONITORING

3.2.1 Soil Physical and Chemical Properties

A variety of soil physical and chemical properties were determined for the soil mixtures, as well as for the original component materials (peat, overburden and tailings sand). A list outlining the number of samples tested per plot or component and the year in which the properties were analyzed is shown in Table 3. In all cases, samples tested were a composite of two or more subsamples per plot. Samples of the soil mixtures were taken from the 0 to 20 cm depth of plots mixed to 20 cm, and from both the 0 to 20 cm and 20 to 40 cm depths of plots mixed to 40 cm. Bulk density was based on 10 cm deep (7 cm diameter) cores extracted from the surface or, in the case of 40 cm mixed plots, from the 20 to 30 cm interval. Analytical methods are summarized in Appendix A.

3.2.2 Soil Moisture

3.2.2.1 Field moisture. Soil moisture was monitored nine times per year at approximately two week intervals during the summers of 1985 to 1989. The surface layer was sampled gravimetrically by extracting soil cores (10 cm deep and 7 cm diameter) near the neutron probe access tubes (two per plot). Subsurface moisture was determined using a neutron probe at six successive 15 cm intervals beginning with the 15 to 30 cm interval and ending with the 90 to 105 cm interval. Two fifteen-second measurements were taken per depth interval. During the course of the study two different probes were used. The first was a Troxler: Model 1255, used from 1985 to mid-1988. This probe malfunctioned after which a second probe (Campbell Pacific Nuclear

Table 3. Soil physical and chemical properties analyzed.

Property	Number of Samples Tested per Plot or Component					
	1984	1985	1986	1987	1988	1989
Original Components						
Particle Size	3	NA[a]	NA	NA	NA	NA
pH and EC	NA	3	NA	NA	NA	NA
Organic C	3	NA	NA	NA	NA	NA
Total N, P, K, S	NA	3	NA	NA	NA	NA
CEC	NA	3	NA	NA	NA	NA
Soil Mixtures						
Particle Size	3	NA	NA	NA	NA	NA
Bulk Density	NA	2	2	NA	NA	NA
Reconstructed Layer Thickness	6	3	3	NA	NA	NA
pH and EC	NA	2	1	1	1	1
Organic C	3	NA	1	NA	NA	1
Total N, P, K, S	NA	2	1	NA	NA	1
Available N, P, K, S	NA	NA	1	1	1	1
CEC	NA	2	NA	NA	NA	NA
Tailings Sand Below the Reconstructed Layer[b]						
Bulk Density	NA	1	NA	NA	NA	NA
pH and EC	NA	1	NA	1	1	1
Availabe N, P, K, S	NA	NA	1	1	1	1
Total N, P, K, S	NA	1	NA	NA	NA	1

[a] NA = Not Analyzed.
[b] Only 1 of the 3 replicates sampled.

Corp.: Model 503) was obtained to complete the measurements for 1988 and 1989. Both probes were calibrated in conjunction with field monitoring.

3.2.2.2 Moisture retention. Moisture retention of the original components as well as the mixtures was measured in 1985. Measurements were taken at 0.1, 0.3, 1, 3, and 15 bar (10, 30, 100, 300, and 1500 kPa) tensions. Three samples of the component materials were tested as well as two samples per plot of the mixtures for the 0 to 20 cm depth of all plots and for the 20 to 40 cm depth of plots mixed to 40 cm. The results for retention at 15 bar were used to determine plant available soil moisture from the field moisture data collected in subsequent years. It is important to note however, that the retention data were based on laboratory prepared (i.e., ground and sieved) samples which were not representative of natural soil structure in the field.

3.2.3 Groundwater

Monitoring of groundwater elevations over the pad began in 1986 with the installation of four observation wells. An additional six wells were installed in 1987 as shown in Figure 6. Wells were constructed of 3 m long, 5 cm diameter slotted PVC tubing. Wells were monitored in conjunction with soil moisture monitoring.

3.2.4 Herbaceous Cover

Percentage aerial cover of species other than the planted trees and shrubs was estimated each summer (in July or August) from 1985 to 1989.

In two of the five monitoring years (1986 and 1989) a detailed quantitative assessment was undertaken in which cover of each species was estimated within 20 cm by 50 cm quadrats. Three quadrats per species subplot

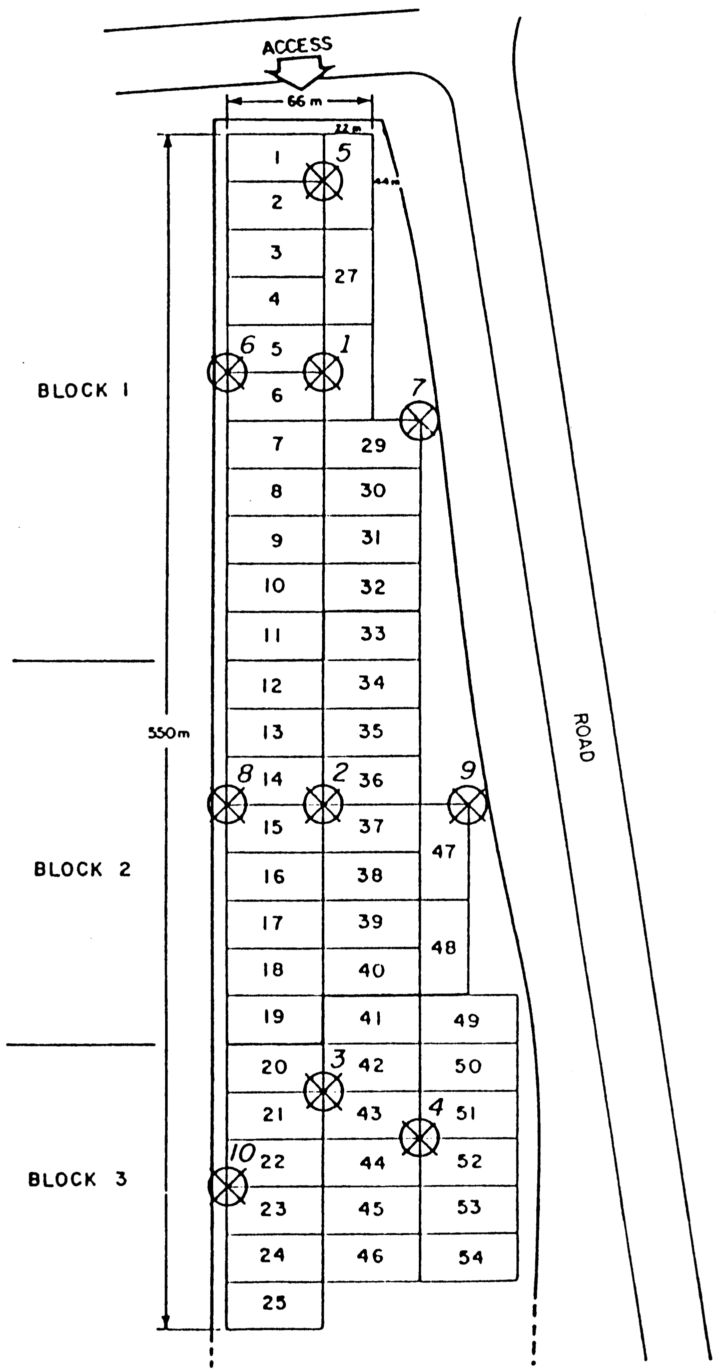


Figure 6. Location of Groundwater Observation Wells.

(i.e., 30 quadrats per plot) were assessed. Cover was categorized according to the following scale:

p	<1 percent	4	26 to 50 percent
1	1 to 5 percent	5	51 to 75 percent
2	6 to 15 percent	6	>75 percent
3	16 to 25 percent		

Based on these estimates, an average cover per species in each plot was determined by assigning the median of the cover category for the species (e.g., 88 percent for category 6) in each quadrat and calculating the mean of all thirty quadrats. It is important to note that cover estimates are based on each species individually and therefore species overlap can result in some quadrats having more than 100 percent total cover.

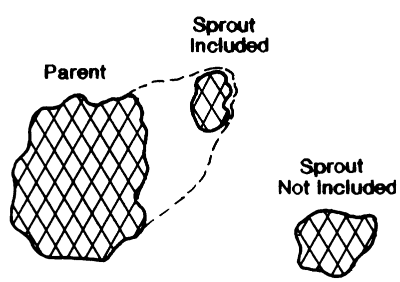
In the remaining years, cover was estimated for all species combined based on a single estimate in each subplot. Cover was ranked on a scale of 1 to 4 that corresponded to approximate 25 percent cover intervals. These semi-quantitative data were used to provide a general indication of the relationship between soil mix and cover of invading species. Consequently they will not be discussed in this report.

3.2.5 Trees and Shrubs

3.2.5.1 Survival. Survival of trees and shrubs was assessed annually in spring (May or June) and again in late August. Every individual was assessed. Percentage survival was then calculated based on the original number of individuals planted per plot (i.e., 40 or 35). In the case of species where replacement planting was done, survival after one year was based on the original stock only, whereas subsequent survival was based on the original plus the replaced individuals.

3.2.5.2 Incidence of disease, insect, and small mammal damage. During the spring survival assessment, indications of plant damage due to disease, insects or small mammals was also noted. Occurrence was then transformed to a percentage based on the number of surviving individuals in the species subplot at the time of the survey.

3.2.5.3 Top growth. Measurements of top growth (height and crown diameter) were taken annually in late August. Height was based on the distance from the ground surface to the base of the uppermost bud, leaf, or needle, when the tallest stem was held in an upright position. Crown diameter was determined by measuring the narrowest and widest points of the plant and converting these measurements into a geometric mean during computer data entry. For species that grew by producing new sprouts from rhizomes (i.e., silverberry, rose, and willow) a neighbouring sprout was only included in the diameter of the presumed parent plant if it was located within a distance not greater than the diameter of the parent. This can be illustrated as follows:



3.2.5.4 Rhizome sprouting. The number of silverberry and willow rhizome sprouts were counted for all plots in August, 1989. Rose sprouts were also tallied but only for plots in Block 1 due to the much greater time required to make an accurate assessment of this species.

3.2.5.5 Rooting. Two assessments of rooting distribution were undertaken during the study but only the more detailed assessment, conducted in 1989, will be addressed in this report. Five randomly selected individuals of each species were excavated from all plots in Block 1. Rooting parameters measured included maximum rooting depth, depth of the root ball, maximum length of a major root (i.e., minimum of approximately 1 mm diameter), air-dried weight, and presence or absence of nodules. Prior to excavation, height and crown diameter were measured. These same characteristics were measured during a preliminary assessment of rooting patterns conducted in 1987, but only one individual of each species per plot in Block 2 was excavated.

3.3 STATISTICAL ANALYSIS AND DATA REDUCTION

Differences in soil and vegetation properties among the amendment treatments were determined by a 3 by 3 by 2 factorial analysis of variance (ANOVA) for a randomized block design. This provided a test of the statistical significance of differences in the mean value of a particular property among each of the factors (mixing depth, peat and overburden application) under study. Interactions between factors are also assessed statistically using this test. Significant interactions indicate that differences observed among levels of one factor are not consistent for all levels of another factor.

The factorial ANOVA test indicates whether at least one of the levels of a particular factor has a significantly different mean value than the other levels. In the case of mixing depth where there are only two levels, this result is sufficient. Where there are three or more levels of a factor, such as with peat and overburden application, another test is required to statistically assess significance of differences between each of the levels. These were tested using Duncan's Multiple Range Test wherever the factorial ANOVA indicated at least one of the levels was different.

Exceptions to the standard 3 by 3 by 2 ANOVA test occurred in a few cases. When soil properties in the 0 to 20 cm and 20 to 40 cm layers of the plots mixed to 40 cm were compared, test results were only reported for differences according to sampling depth. A second exception was the statistical analysis for soil properties in the tailings sand below the reconstructed layer and rhizome sprouting in rose. In these situations only one replicate of each amendment treatment was sampled. For the factorial

ANOVA test, it was assumed that the three-way interaction between mixing depth, peat, and overburden application was negligible so that the error term associated with this interaction could be used to test the significance of differences among the main treatment effects and two-way interactions. This procedure is described in Zar (1984).

Data on rooting characteristics were also analyzed by a 3 by 3 by 2 factorial ANOVA but for a completely randomized design rather than a block design. This was because all five trees per treatment were excavated from the same plot.

Data on growth of willow were analyzed by a 2 by 3 by 2 factorial ANOVA. Due to poor survival of willow in the high overburden treatment, several plots had very few or no remaining individuals. Therefore this treatment was eliminated.

Prior to performing the factorial ANOVA, data were reduced to a single value per plot (except for the rooting data). Tree growth measurements were reduced to a mean value for total height and crown diameter of individuals measured within a species subplot. Similarly moisture content data were averaged for the two locations sampled per plot. Percentage survival in spring was calculated based on all individuals (40 or 35 per plot). Since values of mean survival per plot were frequently in the 90 to 100 percent range, these data were transformed using the arcsine-square root transformation to normalize the data, an assumption of the ANOVA test. The arcsine-square root transformation was also applied to most data expressed as a percentage including:

1. Incidence of disease, insect, and small mammal damage.
2. Soil moisture content.

4. RESULTS

4.1 PHYSICAL AND CHEMICAL PROPERTIES OF THE COMPONENT MATERIALS

Measurements of physical and chemical properties of the original component materials (peat, overburden, and tailings sand) are listed in Table 4. All results are based on analysis of three samples per component which, in turn, consisted of a minimum of ten subsamples.

The peat used for amendment contained a sandy-loam textured mineral fraction which accounted for 70 percent by weight and 13 percent by volume of an average sample. The organic carbon content averaged 14.5 percent (by weight) which is equivalent to 45 percent by weight of the organic matter fraction only. Since application of peat was on a volumetric basis, 87 percent of the applied volume was organic matter of which 45 percent was organic C. This translates to 39 percent organic C delivered, comparable to the 40 percent assumed for the soil reconstruction calculations (Section 3.1.3). In addition to organic C, the peat was the main source of nitrogen and sulphur among the three component materials. Other characteristics included near neutral reaction (pH = 7.4) and low electrical conductivity (EC= 2.0 dS/m).

The overburden amendment was a clay textured material averaging 58.5 percent clay, 24.2 percent silt, and 17.3 percent sand. The clay content was slightly higher than the 50 percent assumed in the soil reconstruction equations. The overburden also had a minor organic C content (0.8 percent). The overburden was the main source of potassium among the components. Additional chemical parameters analyzed on this material indicated that it was non-saline with electrical conductivity averaging 0.4 dS/m, non-sodic (SAR = 0.7), weakly calcareous ($CaCO_3$ = 4.4 percent), and near neutral reaction (pH = 7.6).

The tailings sand was a sand textured material (95 percent sand) with a small amount of residual bitumen (organic C = 0.3 percent). Other nutrient concentrations were extremely low. Note that this material also contained 3.5 percent clay which made it impossible to achieve a 0 percent clay level in any of the reconstructed soils.

Table 4. Physical and chemical properties (Mean ± S.E.) of the component materials.

Property	Peat[a]	Overburden	Tailings Sand
Particle Size (%)			
Sand	70.5 ± 0.1	17.3 ± 4.0	95.4 ± 0.2
Silt	16.0 ± 0.1	24.2 ± 1.5	1.1 ± 0.8
Clay	13.5 ± 0.0	58.5 ± 5.5	3.5 ± 0.8
Total Nutrients (%)			
Organic C	14.5 ± 0.8	0.8 ± 0.1	0.3 ± 0.0
N	0.55 ± 0.08	0.03 ± 0.01	0.007 ± 0.003
P	0.03 ± 0.00	0.03 ± 0.00	0.003 ± 0.000
K	0.24 ± 0.01	0.71 ± 0.02	0.07 ± 0.01
S	0.28 ± 0.02	0.06 ± 0.01	0.03 ± 0.00
$CaCO_3$ Equivalent (%)	ND[b]	4.4 ± 0.2	ND
Sataration Percentage	ND	54.0 ± 3.0	ND
pH	7.4 ± 0.0	7.6 ± 0.0	7.7 ± 0.1
EC (dS/m)	2.0 ± 0.1	0.4 ± 0.1	0.4 ± 0.0
Sodium Adsorption Ratio	ND	0.7 ± 0.1	ND

[a] Peat material contained a mineral fraction that accounted for an average 70 percent by weight (13 percent by volume) of each sample. Results for particle size analysis apply to this mineral fraction.

[b] ND = No Data.

Note: All values based on 3 samples per material.

4.2 PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL MIXTURES

4.2.1 Organic Carbon and Clay Content

Soil was sampled and analyzed for texture and organic C content after plot construction. Results of these analyses (Figure 7) revealed that the overall mean organic C content of the reconstructed soil layer of plots mixed to a depth of 40 cm was significantly ($p<0.01$) higher than of plots mixed to 20 cm. This difference was especially apparent at the highest rate of peat application (i.e., the 5 percent organic C target) which had an average organic C content very similar to the medium application treatment and well below the target value. Clay content in the surface (0 to 20 cm) layer of the 40 cm mixed plots was also significantly ($p<0.01$) higher than that of the 0 to 20 cm layer of the 20 cm mixed plots but only at the high overburden application rate.

Since one of the objectives of soil mixing was to maintain the same soil characteristics in the 0 to 20 cm layer of both 20 cm and 40 cm mixed plots for their respective peat and overburden application treatments, differences noted in organic C and clay content were undesirable results. The differences in organic C content were considered the most serious because the overall mean value was declared significantly different, whereas clay content was only different at the highest overburden application rate. Consequently, a decision was made to increase the organic C content of the plots mixed to 20 cm by adding an additional layer of peat and remixing. Only the plots targeted as 5 percent organic C were reconstructed.

4.2.2 Organic Carbon and Clay Content After Plot Reconstruction

Results of soil analyses for organic C and clay content after plot reconstruction are illustrated in Figure 8. Plot reconstruction elevated the organic C content in the 0 to 20 cm layer of the high peat application plots mixed to 20 cm to an average 4.5 percent compared to the plots mixed to 40 cm which average 3.7 percent. Although the objective was to have the same concentration in each treatment, these results were preferable to that prior

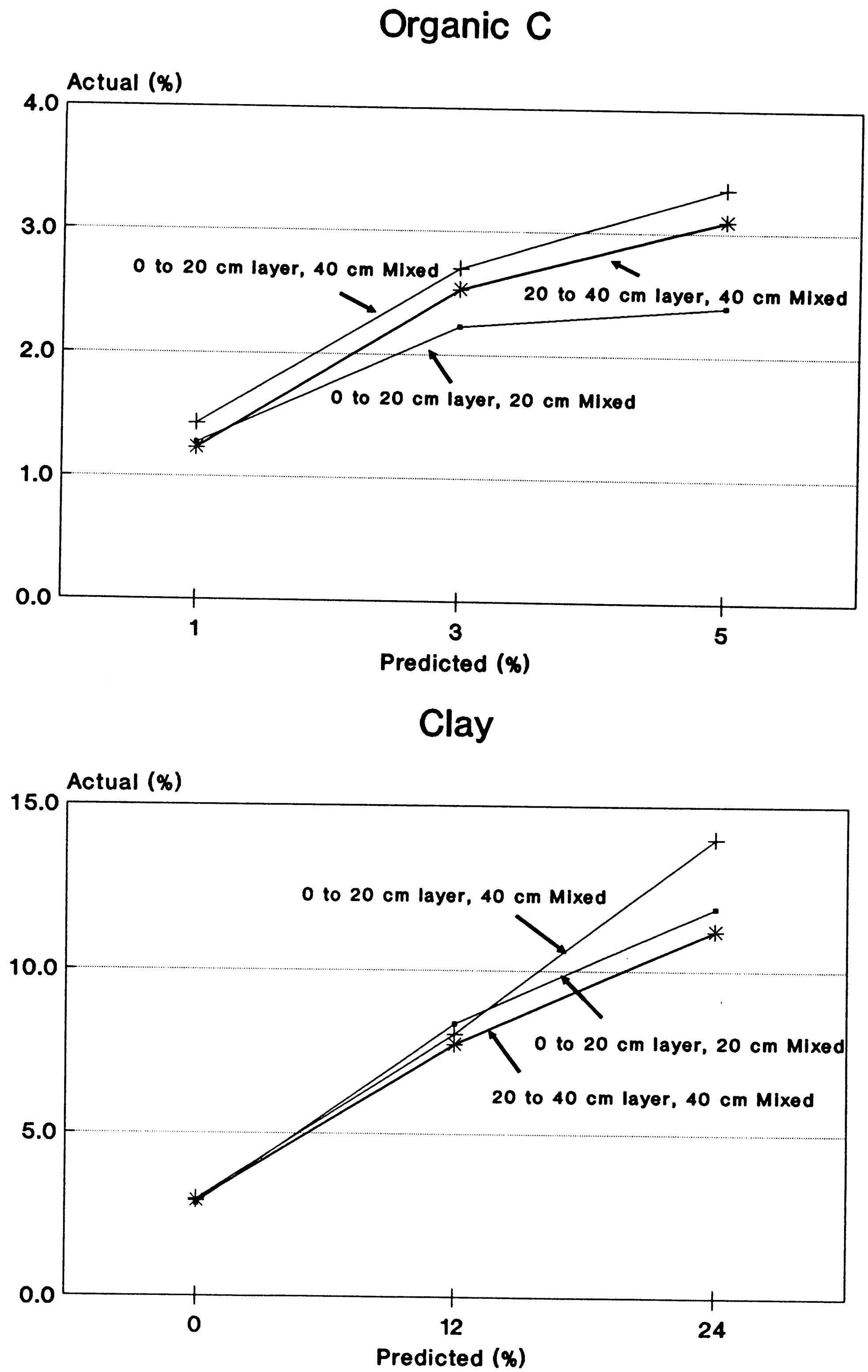
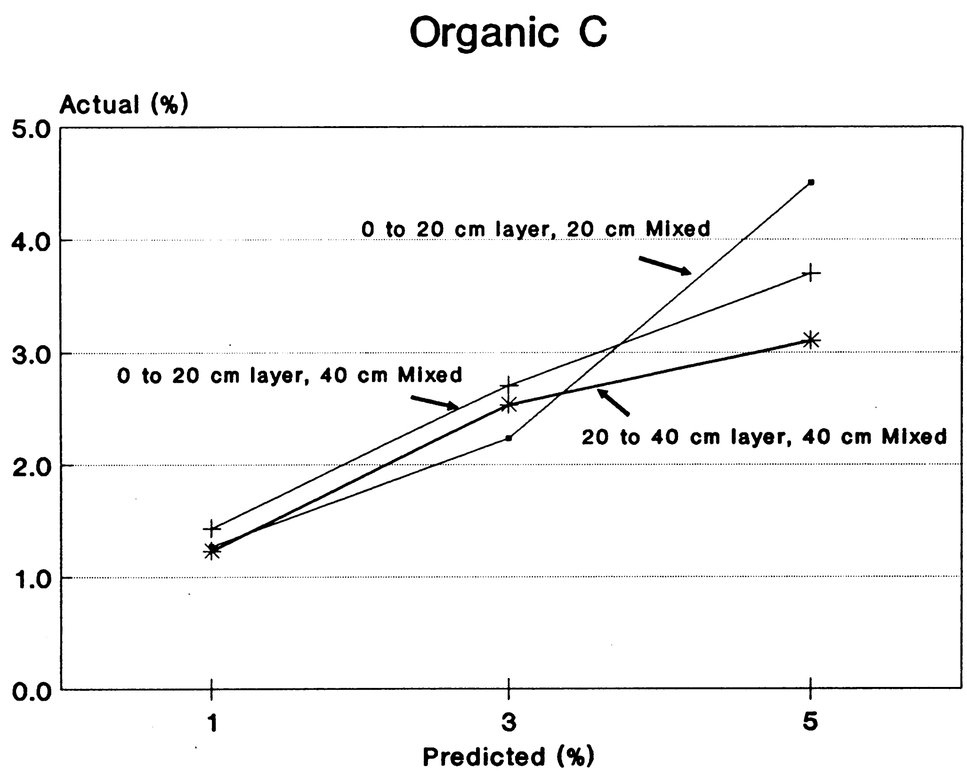


Figure 7. Comparison of Actual to Predicted Concentrations of Organic Carbon and Clay Content After Initial Plot Construction. Values are the Means of Nine Plots.



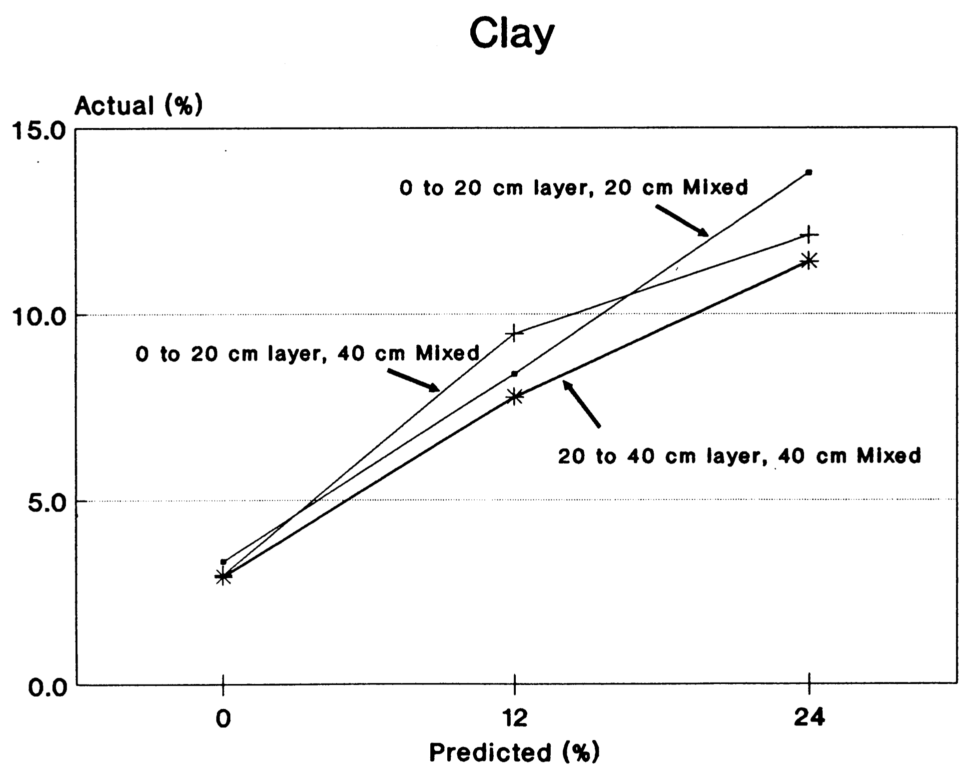


Figure 8. Comparison of Actual to Predicted Concentrations of Organic Carbon and Clay Content After Plot Reconstruction. Values are the Means of Nine Plots.

to reconstruction when there was little difference between the medium and high treatments for the 20 cm mixed plots.

The factorial analysis of variance for these results (Section 4.2.3.2) indicated that the mean organic C content, averaged for both mixing depth treatments, was significantly different ($p<0.01$) among each of the target application rates averaging 1.3 percent, 2.4 percent, and 4.1 percent for the low, medium, and high rates, respectively. The analysis of variance also indicated a significant ($p<0.01$) interaction of mixing depth and peat application on organic C content, due mainly to the difference at the high application level (Figure 8).

Plot reconstruction had a minor impact on clay content among the overburden applications which averaged 3 percent, 9 percent, and 13 percent for the low, medium, and high treatments, respectively, when averaged for both mixing depth treatments. The analysis of variance for these results (Section 4.2.3.1) indicated significant ($p<0.01$) differences among the three application levels and no significant interactions among the three factors under study.

4.2.3 Monitoring Results of the 0 to 20 cm Reconstructed Soil Layer

4.2.3.1 Physical properties. Physical soil properties of the 0 to 20 cm layer are summarized in Table 5 along with results of the factorial analysis of variance. Significant two-way interactions in the analysis of variance are illustrated in Figure B1 (Appendix B). These properties were only assessed at the beginning of the study.

Actual thickness of the reconstructed layer averaged approximately 23 cm and 40 cm for the 20 cm and 40 cm target depths, respectively. As expected, these mean differences were highly significantly different from each other. The analysis of variance also indicated a significantly thicker reconstructed layer for the high peat application treatment at approximately 33 cm, compared to the low and medium treatments that averaged 31 cm. As well, there was a significant interaction of mixing depth and peat application on thickness. These results were due to reconstructing the 20 cm - high peat

Table 5. Physical properties of the 0 to 20 cm reconstructed layer.

Property	Year	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant
		20 cm	40 cm	Low	Med.	High	Low	Med.	High	Interactions
Thickness of Reconstructed Layer (cm)	1985	23^{a}	41^{b}	31^{a}	31^{a}	34^{b}	32^{a}	32^{a}	32^{a}	DP**
	1986	23^{a}	40^{b}	31^{a}	31^{a}	33^{b}	31^{a}	32^{ab}	32^{b}	DP**
Bulk Density (g/cm^3)	1985	1.19^{a}	1.18^{a}	1.32^{c}	1.20^{b}	1.04^{a}	1.19^{a}	1.19^{a}	1.17^{a}	DP**,DO**
	1986	1.13^{a}	1.11^{a}	1.25^{c}	1.12^{b}	0.99^{a}	1.14^{b}	1.13^{b}	1.10^{a}	DP**
Particle Size										
Sand (%)	1984	84^{a}	85^{a}	85^{a}	85^{a}	84^{a}	93^{c}	84^{b}	77^{a}	None
Silt (%)	1984	7^{a}	7^{a}	7^{a}	7^{a}	8^{b}	4^{a}	7^{b}	10^{c}	None
Clay (%)	1984	9^{a}	8^{a}	8^{a}	8^{a}	9^{a}	3^{a}	9^{b}	13^{c}	None

Note: For each property and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Due to rounding, significant differences may occur even though treatments have the same mean value (e.g., thickness).
Values are based on 3 samples per plot except for bulk density (2 per plot).
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

** Probability less than 0.01.

plots. When treatment means were viewed individually, results were as follows:

Reconstructed Layer Thickness (cm) in 1986

Mixing Depth	Low Peat	Medium Peat	High Peat
20 cm	23	23	26
40 cm	40	40	40

Bulk density of the reconstructed layer decreased significantly with peat application from approximately 1.32 g/cm^3 for the low application to 1.04 g/cm^3 for the high. The high overburden application treatment was also declared significantly different at 1.10 g/cm^3 compared to the medium and low applications at 1.13 and 1.14 g/cm^3, respectively for the 1986 assessment. A highly significant interaction of depth and peat application on bulk density was noted for both 1985 and 1986. The nature of this interaction was the same as that for organic C content and reflects the looser soil matrix resulting from increased peat in the 20 cm - high peat treatment compared to the 40 cm - high peat.

Texture of the soil mixtures varied mainly in response to overburden application where differences were highly significant for each of the sand, silt, and clay fractions. Low application (i.e., no overburden) mixtures had a sandy texture (sand fraction = 93 percent) whereas medium and high application treatments had loamy-sand textures (sand fraction = 84 percent and 77 percent, respectively). The only other statistically significant difference noted was a slightly higher silt fraction in the high peat application treatment at 8 percent compared to the medium and low treatments at 7 percent. There was no significant difference between the two mixing depths, nor were there any significant interactions among treatments.

4.2.3.2 Total nutrient concentrations. Total nutrient concentrations of the 0 to 20 cm reconstructed layer are shown in Table 6. Measurements were taken during the first and last years of monitoring. In general, total nutrient

Table 6. Total nutrient concentrations in the 0 to 20 cm reconstructed layer.

Property	Year	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant
		20 cm	40 cm	Low	Med.	High	Low	Med.	High	Interactions
Organic C (%)	1984	2.7^{a}	2.6^{a}	1.3^{a}	2.4^{b}	4.1^{c}	2.4^{a}	2.6^{a}	2.8^{a}	DP**
	1989	2.9^{a}	2.6^{a}	1.5^{a}	2.7^{b}	4.1^{c}	2.5^{a}	2.9^{a}	2.9^{a}	DP**
Total N (%)	1985	0.10^{a}	0.10^{a}	0.05^{a}	0.10^{b}	0.15^{c}	0.10^{a}	0.10^{a}	0.10^{a}	DP**, PO**
	1989	0.15^{a}	0.13^{a}	0.09^{a}	0.13^{a}	0.20^{b}	0.16^{a}	0.13^{a}	0.12^{a}	DP**
Total P (%)	1985	0.013^{a}	0.014^{a}	0.011^{a}	0.013^{b}	0.016^{c}	0.010^{a}	0.013^{b}	0.018^{c}	DP**
	1989	0.017^{a}	0.017^{a}	0.015^{a}	0.018^{a}	0.018^{a}	0.012^{a}	0.018^{b}	0.022^{c}	None
Total K (%)	1985	0.16^{a}	0.17^{a}	0.16^{a}	0.17^{a}	0.17^{a}	0.10^{a}	0.16^{b}	0.24^{c}	None
	1989	0.15^{a}	0.16^{a}	0.15^{a}	0.16^{a}	0.15^{a}	0.09^{a}	0.14^{b}	0.23^{c}	None
Total S (%)	1985	0.08^{a}	0.08^{a}	0.06^{a}	0.08^{b}	0.10^{c}	0.07^{a}	0.08^{ab}	0.09^{b}	DP**, PO**
	1989	0.08^{a}	0.07^{a}	0.05^{a}	0.07^{b}	0.10^{c}	0.07^{a}	0.08^{a}	0.08^{a}	DP**

Note: For each property and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values from 1984 are based on 3 samples per plot, 1985 - 2 per plot, and 1989 - 1 per plot.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

* Probability less than 0.05.
** Probability less than 0.01.

concentrations showed significant differences among peat and overburden treatments in accordance with the relative concentrations of these nutrients in the original amendment materials. There was no significant difference between the two mixing depth treatments for any of the nutrients. As discussed previously, organic C content increased significantly with peat application averaging approximately 1.5, 2.5, and 4.0 percent in the low, medium, and high treatments, respectively. There were no significant differences noted among the other treatments but there was a highly significant interaction of mixing depth and peat application. This interaction is shown in Figure B2 (Appendix B). Organic C content increased slightly between the two sampling intervals, however the significance of this trend was not assessed.

Total nitrogen (N) content increased significantly with peat application, and, in 1985, averaged 0.06 percent, 0.10 percent, and 0.15 percent, respectively. The same trend was noted in 1989 when levels were 0.09 percent, 0.13 percent, and 0.20 percent. It is also noteworthy that all treatment means were, on average, 30 percent higher in 1989.

Total phosphorus (P) increased significantly with both peat and overburden application. In 1985 values ranged from 0.011 percent to 0.016 percent among peat applications and from 0.010 percent to 0.018 percent for overburden. Slight increases were noted for all treatment means in 1989.

Total potassium (K) increased significantly with overburden application averaging 0.10 percent, 0.16 percent, and 0.24 percent in the low, medium, and high applications, respectively in 1986. Values were essentially unchanged in 1989.

Total sulphur concentrations increased significantly with peat application from approximately 0.05 percent for the low to 0.10 percent for the high application both in 1985 and 1989. Smaller increases were noted for overburden applications (0.07 percent to 0.09 percent).

For nutrients in which significant differences were noted among peat treatments (N, P, and S), a significant interaction of mixing depth and peat application was also indicated. These are illustrated in Figure B2 (Appendix B) for the 1985 data. In all cases the nature of the interaction resembles that found for organic C content, an indication that concentrations of these nutrients are highly correlated with organic matter content. Significant interactions of peat and overburden application on total N and S content were also indicated but only for the 1985 data (Figure B2, Appendix B). The reasons for these apparent interactions are unknown.

4.2.3.3 pH, electrical conductivity and plant available nutrients. Soil reaction, electrical conductivity and available nutrient supply were monitored several times during the study. Differences among treatments were consistent from year to year and therefore, only results obtained in 1989 are shown (Table 7). There were no apparent trends in any of the parameters with time.

Soil pH was very uniform among treatments with means ranging from 7.5 to 7.8 over the five years of the study. Significant differences were noted throughout the study but, in a practical sense, these differences were negligible.

Electrical conductivity was low, with means ranging from 0.3 to 1.3 dS/m over the five years of the study. EC increased significantly with peat application although, as with pH, the magnitude of the difference was small and likely had no influence on plant establishment.

Available nitrogen supply was very low for all treatments but significant differences were observed among peat application levels. In 1989, available N increased from 0.4 ppm to 1.0 ppm as peat application increased from low to high.

Available P content was very uniform among treatments and over time. Values ranged from 2.6 to 4.7 ppm and there were no significant differences among treatments.

Available K increased significantly with both peat and especially overburden application. In the 1989 results, mean values ranged from 28 up to 51 ppm as overburden application increased from low to high. With peat application available K increased from 34 to 44 ppm.

Available S content generally varied from 25 to 50 ppm over the years. In 1989 there were no significant differences among treatments. However, in the previous years of monitoring the high peat application had a

Table 7. pH, electrical conductivity, and plant available nutrients in the 0 to 20 cm reconstructed layer.

Property	Year	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)		
		20 cm	40 cm	Low	Med.	High	Low	Med.	High
pH	1989 Mean	7.7[a]	7.7[a]	7.5[a]	7.7[b]	7.6[b]	7.7[a]	7.7[ab]	7.8[b]
	1985 to 1989	7.5 to 7.6	7.5 to 7.6	7.5 to 7.7	7.5 to 7.7	7.5 to 7.6	7.5 to 7.7	7.6 to 7.7	7.5 to 7.8
EC (dS/m)	1989 Mean	0.5[a]	0.6[a]	0.4[a]	0.5[ab]	0.8[b]	0.5[a]	0.5[a]	0.5[a]
	1985 to 1989	0.3 to 1.1	0.3 to 1.1	0.3 to 0.9	0.3 to 1.2	0.4 to 1.3	0.3 to 1.1	0.4 to 1.2	0.4 to 1.1
N (ppm)	1989 Mean	0.6[a]	0.8[a]	0.4[a]	0.7[a]	1.0[b]	0.7[a]	0.8[a]	0.6[a]
	1986 to 1989	0.6 to 1.1	0.8 to 1.1	0.4 to 0.9	0.7 to 1.1	1.0 to 1.8	0.7 to 1.1	0.8 to 1.2	0.6 to 1.3
P (ppm)	1989 Mean	2.9[a]	2.8[a]	2.9[a]	2.8[a]	2.8[a]	2.6[a]	3.0[a]	2.9[a]
	1986 to 1989	2.9 to 4.7	2.8 to 4.2	2.9 to 4.7	2.8 to 4.5	2.8 to 4.1	2.6 to 4.3	3.0 to 4.5	2.9 to 4.6
K (ppm)	1989 Mean	38[a]	40[a]	34[a]	39[ab]	44[b]	28[a]	39[b]	51[c]
	1986 to 1989	38 to 50	35 to 51	34 to 49	29 to 51	43 to 56	28 to 37	34 to 53	41 to 71
S (ppm)	1989 Mean	28[a]	28[a]	25[a]	32[a]	27[a]	25[a]	30[a]	29[a]
	1986 to 1989	28 to 46	28 to 38	7 to 25	28 to 38	27 to 66	25 to 44	27 to 48	29 to 47

Note: For each property and factor, values followed by the same letter are not significantly different from each other at the 95% significance level. There were no significant interactions for any of the properties shown in this table.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.
Values for 1985 (or 1986) to 1989 represent the minimum and maximum means during the time period.

significantly higher available S content compared to the low and medium applications.

4.2.4 Comparison of the 0 to 20 cm and 20 to 40 cm Layers of Plots Mixed to 40 cm

Physical and chemical properties of the upper and lower reconstructed soil layers of plots mixed to 40 cm are given in Table 8. Physical properties (bulk density and texture) were only assessed once, whereas most of the chemical properties were monitored for several years.

Bulk density was slightly lower in the surface 0 to 20 cm layer at 1.2 g/cm^3, compared to 1.3 g/cm^3 in the 20 to 40 cm layer. Clay content was significantly higher in the surface at 8.3 percent compared to the lower layer at 7.4 percent.

Reaction of the surface layer at pH 7.7 was significantly higher than the lower layer at pH 7.6. Electrical conductivity was lower in the surface at 0.6 dS/m compared to the value of 1.0 dS/m in the layer below.

There were no significant differences in total nutrient concentrations between the upper and lower reconstructed layers but there were significant differences noted in plant available nutrient supply. Included were significantly higher available N (0.8 versus 0.5 ppm) and K (40 versus 32 ppm) concentrations in the surface layer compared to that below. Available S content was significantly higher in the lower portion of the profile at 72 ppm compared to the upper portion at 28 ppm.

Note that the differences in Table 8 are those found in 1989. However, most of these differences have been noted throughout the study including those for pH, electrical conductivity, available N, and S. The elevated available K in the surface layer was noted in 1988 and 1989 only.

4.2.5 Properties of the Tailings Sand Below the Reconstructed Layer

Physical and selected chemical properties including pH, EC, and plant available nutrient concentrations of the tailings sand immediately below

Table 8: Soil properties in the 0 to 20 cm and 20 to 40 cm reconstructed layers in plots mixed to a depth of 40 cm.

		Reconstructed Layer	
Property	Year	0 to 20 cm	20 to 40 cm
Bulk Density (g/cm^3)	1985	1.2[a]	1.3[b]
Clay (%)	1985	8.3[b]	7.4[a]
pH	1989 Mean	7.7[b]	7.6[a]
	1985 to 1989	7.5 to 7.7	7.4 to 7.6
EC (dS/m)	1989 Mean	0.6[a]	1.0[b]
	1985 to 1989	0.3 to 1.1	0.5 to 1.5
Organic C (%)	1989 Mean	2.6[a]	2.1[a]
	1985 to 1986	2.6 to 2.8	2.1 to 2.4
Available N (ppm)	1989 Mean	0.8[b]	0.5[a]
	1986 to 1987	0.8 to 1.1	0.5 to 1.1
Total N (%)	1989 Mean	0.13[a]	0.11[a]
	1985 to 1986	0.10 to 0.13	0.09 to 0.11
Available P (ppm)	1989 Mean	2.8[a]	2.9[a]
	1986 to 1988	2.8 to 4.2	2.9 to 4.0
Total P (%)	1989 Mean	0.017[a]	0.014[a]
	1985 to 1989	0.014 to 0.017	0.013 to 0.015
Available K (ppm)	1989 Mean	40[b]	32[a]
	1986 to 1989	35 to 51	32 to 48
Total K (%)	1989 Mean	0.16[a]	0.13[a]
	1985 to 1989	0.11 to 0.17	0.11 to 0.15
Available S (ppm)	1989 Mean	28[a]	72[b]
	1986 to 1989	28 to 38	63 to 92
Total S (%)	1989 Mean	0.07[a]	0.07[a]
	1985 to 1989	0.07 to 0.08	0.07 to 0.08

Note: For each property, values followed by the same letter are not significantly different from each other at the 95% significance level. Values are the mean of 27 plots. Values for 1985 (or 1986) to 1989 represent the minimum and maximum means during the time period.

the reconstructed soil are given in Table 9, while total nutrient concentrations are shown in Table 10. There were no statistically significant interactions of any of the treatments for these properties.

There was a slight, but statistically significant decrease in bulk density of the tailings sand with increasing peat application, values declining from 1.58 to 1.54 g/cm^3 as application increased from low to high. Significant differences of the same magnitude were also noted among overburden applications but there was no trend with application level.

Clay content averaged 2 percent with no significant differences among treatments. Reaction ranged from pH 7.8 to 8.2 with significant increases noted with overburden application. The sand beneath the 40 cm mixed treatments also had a significantly higher pH at 8.0 but by only 0.1 units compared to the 20 cm mixed treatments at pH 7.9.

Electrical conductivity averaged 0.3 dS/m for all treatment means in 1989 and never exceeded 1 dS/m throughout the five years of monitoring.

Plant available nutrient concentrations were generally much lower in the underlying tailings sand than in the reconstructed soil at the surface. Available N in 1989 averaged 0.1 to 0.2 ppm with no significant differences noted among treatments. In previous years, concentrations never exceeded the detection limit of 0.5 ppm. (Improved instrumentation accounts for the lower detection limit in 1989.) Available P content averaged 2.2 to 2.4 ppm and remained consistently low and unaffected by treatment throughout the study. Likewise, available K ranged from 15 to 17 ppm and, although more variable than available P, has not been influenced by treatment. Available S content was the most variable nutrient in 1989 ranging from 6 to 16 ppm and increased significantly with peat application. This trend was observed in previous years but was not statistically significant, probably because of the limited sample size (one replicate per treatment). Total nutrient concentrations, assessed in 1985 and 1989, were very low and showed no apparent change between the two assessments (Table 10). There were no significant differences in total nutrient content among any of the treatments.

Table 9. Physical and selected chemical properties of the tailings sand below the reconstructed layer.

Property	Year	Mixing Depth		Peat Application			Overburden Application		
		20 cm	40 cm	Low	Med.	High	Low	Med.	High
Bulk Density (g/cm^3)	1985	1.55^{a}	1.57^{a}	1.58^{b}	1.56^{ab}	1.54^{a}	1.58^{b}	1.54^{a}	1.56^{ab}
Clay (%)	1984	2.0^{a}	2.0^{a}	2.0^{a}	2.0^{a}	2.1^{a}	1.9^{a}	2.1^{a}	2.1^{a}
pH	1989 Mean	7.9^{a}	8.0^{b}	8.0^{a}	8.0^{a}	7.9^{a}	7.8^{a}	8.0^{ab}	8.2^{b}
	1985 to 1989	7.4 to 8.0	7.2 to 8.0	7.3 to 8.0	7.3 to 8.0	7.3 to 8.0	7.2 to 7.9	7.2 to 8.0	7.5 to 8.2
EC (mS/cm)	1989 Mean	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}
	1985 to 1989	0.3 to 0.4	0.3 to 0.6	0.3 to 0.6	0.3 to 0.5	0.3 to 0.6	0.3 to 0.7	0.3 to 0.5	0.3 to 0.5
Available N (ppm)	1989 Mean	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.2^{a}	0.1^{a}	0.2^{a}	0.2^{a}
	1986 to 1989	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Available P (ppm)	1989 Mean	2.3^{a}	2.2^{a}	2.3^{a}	2.4^{a}	2.2^{a}	2.3^{a}	2.3^{a}	2.3^{a}
	1986 to 1989	2.3 to 3.7	2.2 to 3.7	2.3 to 3.9	2.4 to 3.6	2.2 to 3.6	2.3 to 4.0	2.3 to 3.6	2.3 to 3.5
Available K (ppm)	1989 Mean	15^{a}	17^{a}	17^{a}	15^{a}	16^{a}	16^{a}	16^{a}	16^{a}
	1986 to 1989	15 to 30	17 to 26	17 to 26	15 to 40	16 to 24	16 to 23	16 to 23	16 to 44
Available S (ppm)	1989 Mean	11^{a}	11^{a}	6^{a}	11^{ab}	16^{b}	13^{a}	10^{a}	10^{a}
	1986 to 1989	7 to 14	9 to 20	6 to 25	6 to 8	11 to 19	7 to 29	7 to 16	5 to 10

Note: For each property and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
There were no significant interactions for any of the properties shown in this table.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.
Values for 1985 (or 1986) to 1989 represent the minimum and maximum means during the time period.

* All available N concentrations were below the lower detection limit of 0.5 ppm in years prior to 1989.

Table 10. Total nutrient concentrations of the tailings sand below the reconstructed layer.

Property	Year	Mixing Depth		Peat Application			Overburden Application		
		20 cm	40 cm	Low	Med.	High	Low	Med.	High
Total N (%)	1985	0.01[a]	0.01[a]	0.01[a]	0.01[a]	0.01[a]	0.01[a]	0.01[a]	0.01[a]
	1989	0.01[a]	0.01[a]	0.01[a]	0.01[a]	0.02[a]	0.01[a]	0.02[a]	0.01[a]
Total P (%)	1985	0.003[a]	0.003[a]	0.003[a]	0.003[a]	0.004[a]	0.003[a]	0.004[a]	0.004[a]
	1989	<0.01[a]	<0.01[a]	<0.01[a]	<0.01[a]	<0.01[a]	<0.01[a]	<0.01[a]	<0.01[a]
Total K (%)	1985	0.06[a]	0.06[a]	0.05[a]	0.07[a]	0.07[a]	0.07[a]	0.06[a]	0.06[a]
	1989	0.05[a]	0.05[a]	0.05[a]	0.05[a]	0.05[a]	0.05[a]	0.05[a]	0.06[a]
Total S (%)	1985	0.03[a]	0.03[a]	0.03[a]	0.04[a]	0.03[a]	0.03[a]	0.03[a]	0.03[a]
	1989	0.03[a]	0.03[a]	0.04[a]	0.03[a]	0.03[a]	0.03[a]	0.03[a]	0.03[a]

Note: For each property and factor, values followed by the same letter are not significantly different from each other at the 95% significance level. There were no significant interactions for any of the properties shown in this table.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

4.3 PRECIPITATION AND SOIL MOISTURE

4.3.1 Precipitation and Temperature

Data for monthly precipitation and temperature during the five years of the study are given in Table 11. The data were collected at the Fort McMurray airport, approximately 50 km south of the study site.

Total annual precipitation during the first three years of the study ranged from 391.2 to 412.2 mm, well below the thirty year average of 471.9 mm. Similarly, precipitation during the growing season (May to August) ranged from 196.7 to 216.7 mm compared to the long term average of 252.4 mm. During the last two years of the study, precipitation exceeded the thirty year averages with total values of 509.9 and 515.0 mm and growing season values of 333.1 and 304.4 mm for 1988 and 1989, respectively.

Mean monthly temperatures during the growing season were much less variable than precipitation. For a given month, mean temperatures seldom varied by more than 3°C during the five years of the study. Temperatures were generally slightly above the thirty year average for the area.

4.3.2 Relationships among Precipitation, Soil Moisture and Water Table Elevations

Precipitation, soil moisture and water table elevations during the study are summarized in Figure 9. Changes in surface moisture (0 to 15 cm) showed little resemblance to precipitation patterns. The two years with the highest average surface moisture (1985 and 1986) were among the lowest in precipitation during the growing season. This suggests that surface moisture changed rapidly in response to rainfall and drought conditions and that these changes were not noticed when sampling was done at two week intervals. Surface moisture was generally higher in the early part of the growing season (May and June) when values typically ranged from 20 to 28 mm/15 cm or more before declining to values in the 10 to 20 mm/15 cm range in July and August.

A close relationship is apparent between precipitation and moisture in the profile to a depth of 105 cm (determined by adding field measurements from the seven successive 15 cm depth intervals). The two years with the

Table 11. Monthly precipitation and mean monthly temperature at Fort McMurray.

Month	Monthly Precipitation (mm)						Monthly Temperature (°C)					
	1951 to 1980	1985	1986	1987	1988	1989	1951 to 1980	1985	1986	1987	1988	1989
Jan.	22.7	12.4	34.4	20.3	32.9	19.6	-21.8	-14.3	-9.5	-9.2	-19.4	-16.5
Feb.	18.8	16.4	5.0	30.0	12.0	6.0	-15.4	-20.1	-14.6	7.4	-14.7	-15.4
Mar.	20.7	8.7	7.6	37.4	18.2	25.1	-9.2	-2.7	-3.3	-8.7	-4.0	-13.4
Apr.	20.5	46.3	34.7	10.4	28.0	4.8	2.1	3.5	2.3	6.2	3.9	1.9
May	36.3	63.0	31.3	25.6	16.8	77.6	9.7	11.3	11.6	11.1	10.7	9.9
June	64.1	49.4	31.3	56.9	99.1	91.8	14.0	13.2	14.6	15.5	15.9	14.4
July	75.4	57.2	134.0	31.1	118.4	107.1	16.4	16.1	16.2	17.3	16.6	18.3
Aug.	76.6	27.1	20.1	86.6	89.8	27.9	14.8	14.3	15.2	13.1	15.7	17.4
Sept.	58.5	51.9	21.2	31.3	12.4	71.6	9.0	7.2	9.1	12.4	9.5	10.6
Oct.	28.1	38.8	27.6	30.4	29.1	17.1	3.3	1.4	3.8	3.7	3.3	3.4
Nov.	25.2	10.1	32.3	6.5	28.4	41.5	-8.2	-16.3	-13.6	-3.7	-8.9	-12.8
Dec.	25.0	30.9	11.7	27.8	15.8	24.9	-17.0	-12.8	-8.6	-11.3	-13.5	-17.3
Total	471.9	412.2	391.2	394.3	509.9	515.0						
May to August	252.4	196.7	216.7	200.2	333.1	304.4	13.7	13.7	14.4	14.3	14.7	15.0

Data from Atmospheric Environment station at the Fort McMurry airport.

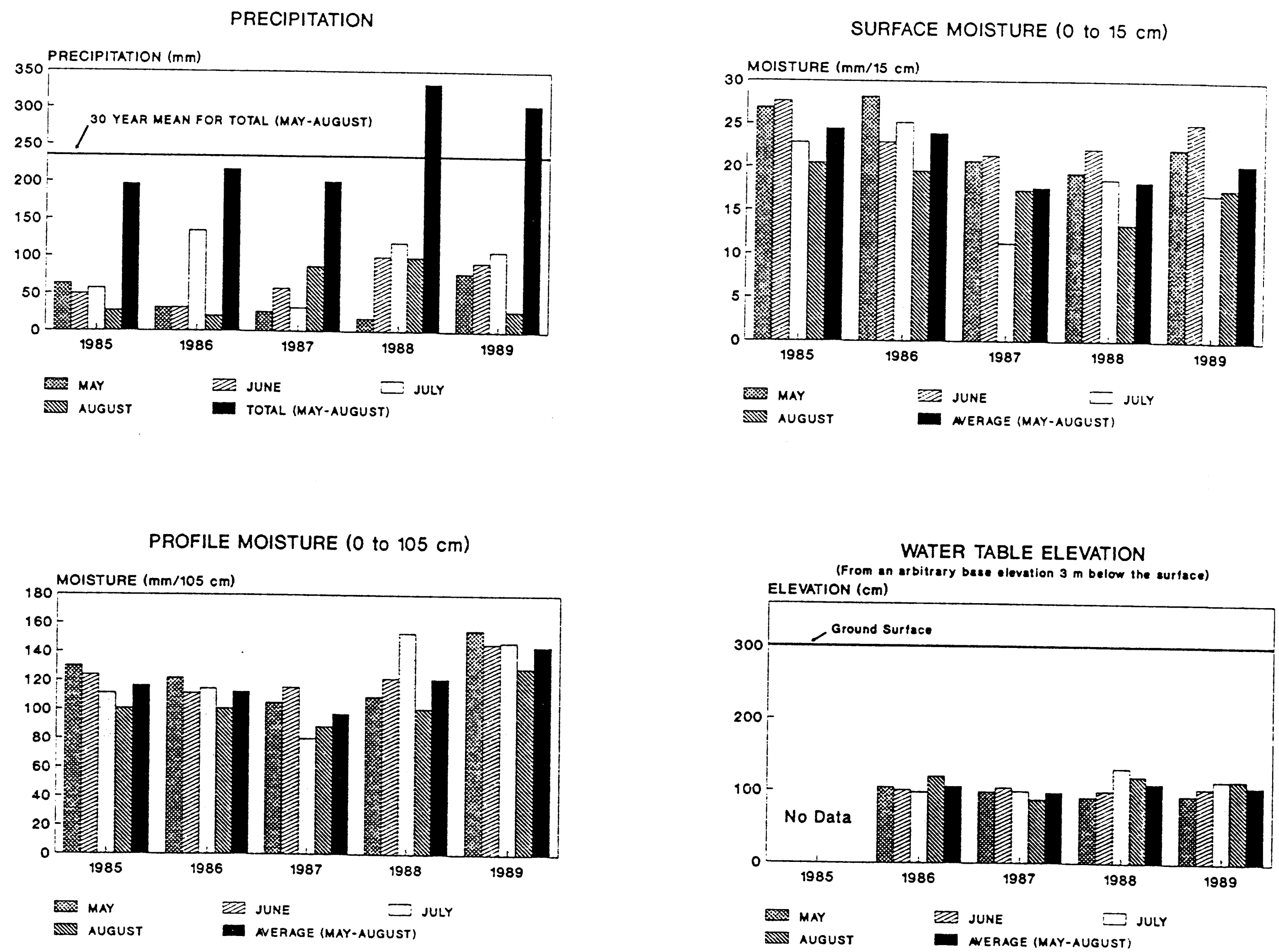


Figure 9. Precipitation, Soil Moisture and Water Table Elevations.

highest average moisture in the profile (1988 and 1989) were also those with the highest precipitation. In these years monthly moisture typically ranged from 120 to 150 mm/105 cm compared to values of 80 to 120 mm/105 cm in the first three years.

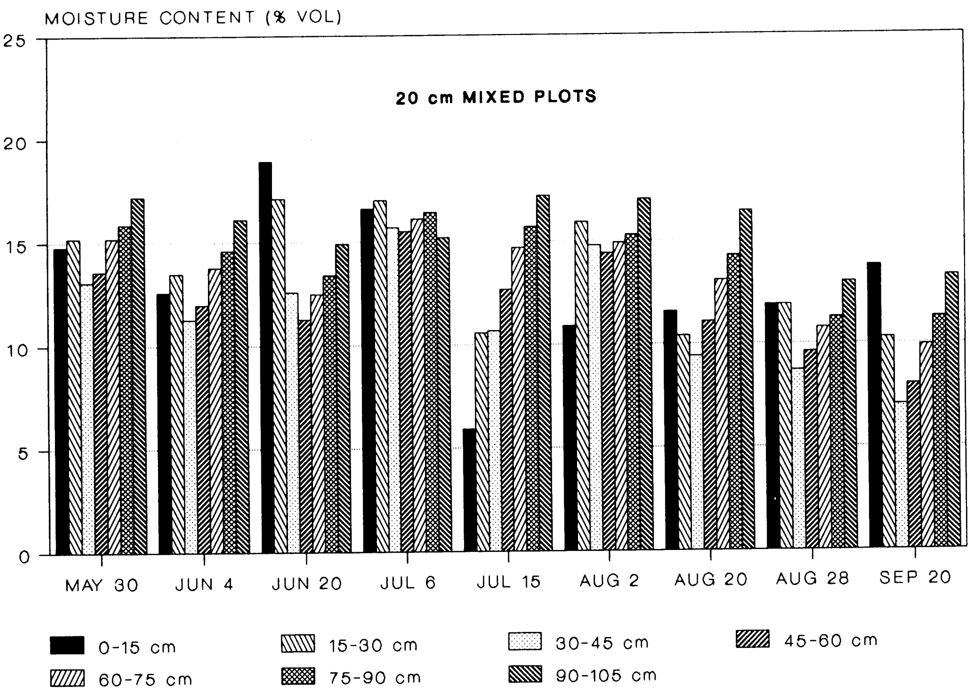
Fluctuations in the depth to the water table were also influenced by precipitation during the growing season. Depth averaged approximately 200 cm below the surface in May each year. There was a tendency for the water table to fall slightly during the dry summer months of 1987 and 1988 whereas the wet summers of 1988 and 1989 caused the water table to rise by as much as 50 cm.

4.3.3 Distribution Throughout the 0 to 105 cm Profile

The distribution of moisture throughout the surface metre is illustrated in Figure 10. Separate profiles are shown for the 20 cm and 40 cm mixed plots during the summer of 1989. After reviewing all moisture data collected during the study, the profiles shown are those that best illustrate the influence of treatment (mixing depth) and precipitation on moisture distribution.

Some general trends observed throughout the study and apparent in most of the profiles shown in Figure 10 include the following:

1. Moisture content in the surface 0 to 15 cm depth was the same in plots mixed to 20 cm as those mixed to 40 cm.
2. In the plots mixed to 20 cm the highest moisture content was usually in the deepest layers (eg., 75 to 105 cm) whereas in the plots mixed to 40 cm the highest moisture content was almost always in the surface layers (0 to 45 cm).
3. The driest interval was usually immediately below the reconstructed soil (i.e., the 30 to 45 cm interval of plots mixed to 20 cm and the 45 to 60 cm interval of plots mixed to 40 cm).
4. Below the reconstructed layer moisture increased with depth reflecting the influence of the water table often within 2 m of the surface.



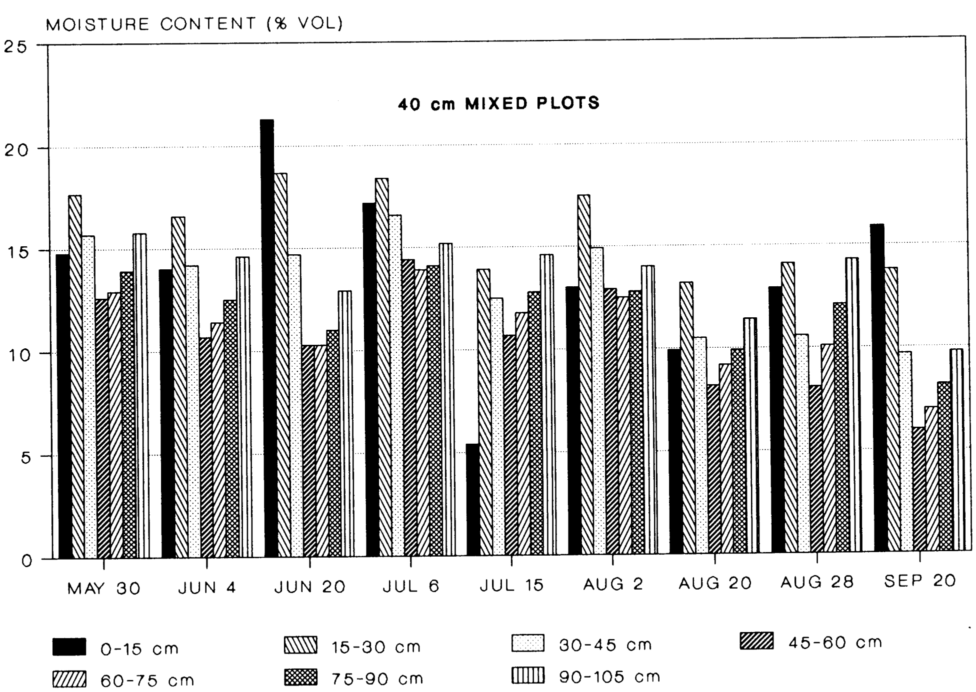


Figure 10. Distribution of Moisture in the 0 to 105 cm Profile During the Summer of 1989.

Distribution patterns shown for late May and early June reflect these general trends. In late June moisture content increased in the surface layers in response to rainfall while moisture in the lower layers continued to decrease. Continuous heavy rainfall through June and early July increased the moisture content of all soil layers to approximately 15 percent (by volume) in both the 20 and 40 cm mixed plots. As indicated in Section 4.3.4.1, the tailings sand layers were probably at or very close to saturation at this time.

Hot, dry weather during early to mid July resulted in a decline of surface moisture levels to approximately 6 percent, in both the 20 and 40 cm mixed plots, by July 15. These were the lowest recorded during the study.

Heavy rainfall during late July to early August caused surface moisture levels to rise markedly, but had little influence on moisture content of lower depths (60 to 105 cm).

From late August to September moisture contents declined below ten percent in the mid-depths for the first time in the season in response to the dry August conditions. Rainfall received during this time appears to have been retained in the surface layers which generally had moisture in excess of 10 percent, especially the plots mixed to 40 cm.

4.3.4 Moisture Retention

4.3.4.1 Moisture retention of the component materials. Moisture retention over the range of 1/10 to 15 bar for the individual component materials is shown in Table 12 and illustrated in Figure 11. Inconsistencies for the tailings sand are apparent as indicated by the lower retention for 1/10 bar tension (6 percent) compared to that at 1/3, 1, and 3 bar (13, 10 and 7 percent, respectively). A review of field data (Figure 10) shows moisture contents as high as 17 percent in tailings sand below the reconstructed layer indicating that the 1/10 bar value is incorrect. The estimated value from the graph (Figure 11) would be approximately 20 percent.

Moisture retention for the overburden and especially the peat was consistently higher at all tensions than the tailings sand. Of particular

Table 12. Moisture retention (percent by volume) of the original component materials.

Tension (bar)	Peat		Overburden		Tailings Sand	
	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
1/10	65 ± 4	58 to 70	44 ± 1	42 to 46	6 ± 0	6 to 7
1/3	54 ± 4	47 to 59	38 ± 2	34 to 40	13 ± 0	13 to 14
1	46 ± 3	40 to 49	33 ± 2	30 to 36	10 ± 1	8 to 11
3	28 ± 2	24 to 32	25 ± 1	24 to 27	7 ± 0	7 to 8
15	27 ± 2	23 to 29	23 ± 1	22 to 24	1 ± 0	1 to 1

Note: All results based on 3 samples.

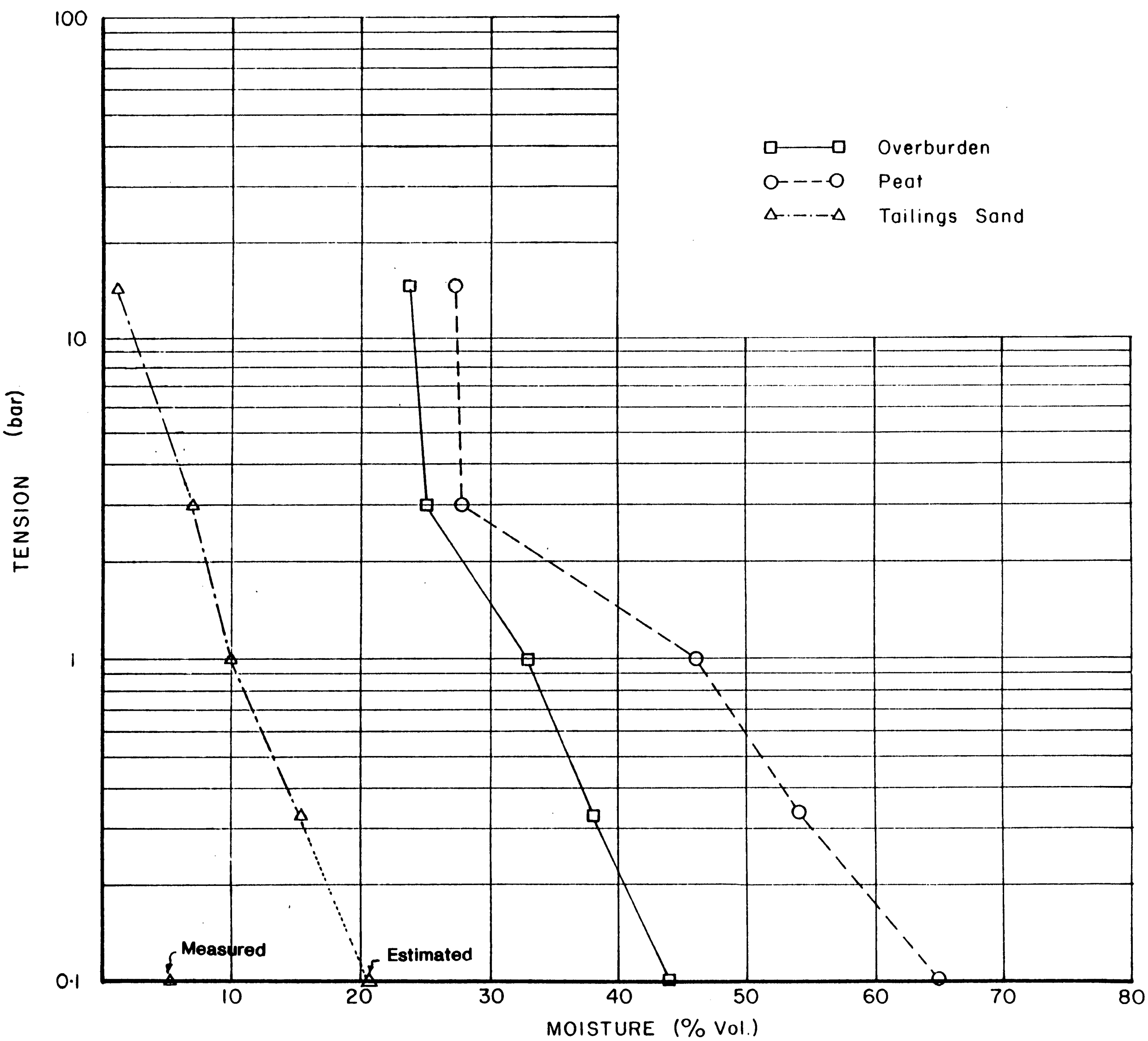


Figure 11. Moisture Retention of the Component Materials.

importance, with respect to moisture holding capacities of the materials, was the difference between the moisture retained at 1/3 bar and 15 bar tensions, commonly referred to as plant available moisture. Plant available moisture for the tailings sand, overburden, and peat were 12, 15, and 27 percent, respectively.

4.3.4.2 <u>Moisture retention of the 0 to 20 cm reconstructed layer</u>. Table 13 presents the results of the factorial ANOVA for mean soil moisture retention in the upper 20 cm reconstructed layer. Moisture retention curves for the various mixes are shown in Figure 12. It is important to note that the data are based on laboratory prepared (ground and sieved) samples.

In general, results show that increasing amounts of peat and overburden increased the retention (water holding capacity) at all tensions. Furthermore, the magnitude of the increase was similar for both peat and overburden application. The lowest soil moisture contents at all tensions were recorded in the low overburden-low peat treatments, ranging from 17 percent at 1/10 bar to 3 percent at 15 bar (Figure 12). Highest contents were recorded in the high peat and overburden treatment where values ranged from 35 percent to 11 percent at 1/10 and 15 bars, respectively (Figure 12).

At low tensions (1/10 and 1/3 bar) samples of the 0 to 20 cm layer of plots mixed to 40 cm had significantly higher retention than the 0 to 20 cm layer of plots mixed to 20 cm (Table 13). This trend was evident but the differences were not significant at higher tensions (1, 3, and 15 bar).

Plant available moisture capacity of the reconstructed soils was affected mainly by peat application, increasing significantly from 13.4 percent for the low application to 17.4 percent for the high. There was also a trend toward increasing capacity with overburden application (15.1 to 16.2 percent) but the differences were not statistically significant. An unexpected result was a significantly higher capacity for the surface layer of plots mixed to 40 cm compared to that of plots mixed to 20 cm (16.6 versus 14.7 percent).

A significant interaction of peat and overburden on moisture retention was indicated in the statistical analysis of the data for all but

Table 13. Moisture retention (percent by volume) of the 0 to 20 cm reconstructed layer.

	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant
Tension (bar)	20 cm	40 cm	Low	Med.	High	Low	Med.	High	Interactions
1/10	27.1[a]	29.1[b]	24.2[a]	28.4[b]	31.5[c]	24.1[a]	28.3[b]	31.7[c]	PO*
1/3	22.9[a]	25.3[b]	20.0[a]	24.8[b]	27.6[c]	21.9[a]	23.9[ab]	26.6[b]	PO*
1	17.7[a]	19.4[a]	14.9[a]	19.2[b]	21.7[c]	16.6[a]	17.9[a]	21.2[b]	None
3	12.2[a]	13.0[a]	10.0[a]	12.9[b]	15.0[c]	10.9[a]	12.1[a]	14.9[b]	PO*
15	8.2[a]	8.8[a]	6.6[a]	8.6[b]	10.2[c]	6.8[a]	8.3[b]	10.4[c]	PO*, DP*
1/3 - 15 (plant available)	14.7[a]	16.6[b]	13.4[a]	16.2[b]	17.4[b]	15.1[a]	15.6[a]	16.2[a]	PO*

Note: For each tension and factor, values followed by the same letter are not significantly different from each other at the 95% significance level. Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots. Two measurements were made per plot.

* Probability less than 0.05.

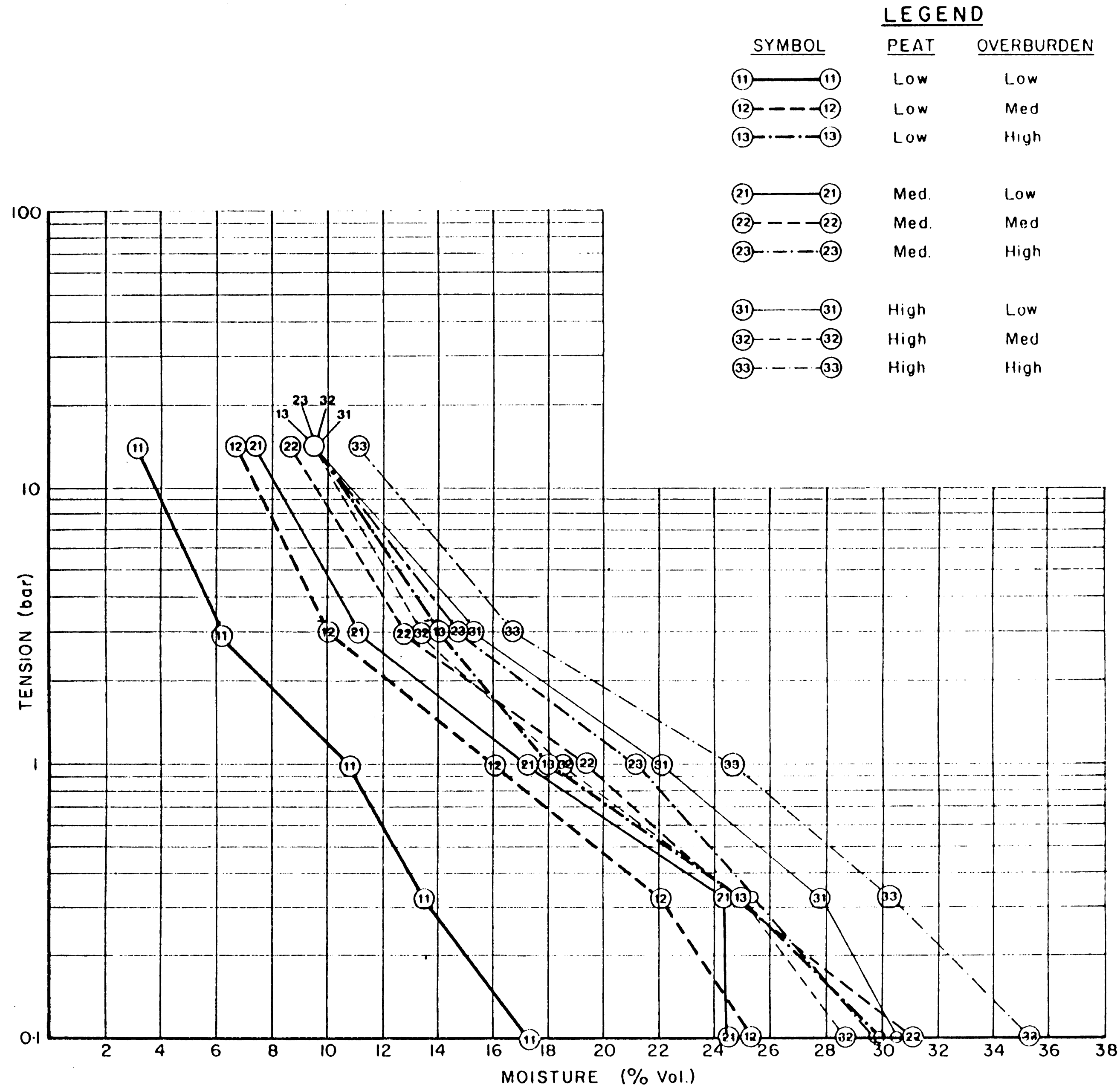


Figure 12. Moisture Retention of the Soil Mixtures.

the 1 bar tension. When the nature of these interactions was investigated more closely (Figure B3, Appendix B), it became apparent that addition of overburden had more influence on increasing moisture retention when the reconstructed soil had low peat but that the effect was less pronounced or not apparent as peat increased from medium to high. Likewise, at low applications of overburden the effect of the addition of peat was more pronounced than when the overburden content was high.

4.3.5 Moisture Content Among Treatments

Statistical analysis of moisture content among treatments in 1989 is summarized in Table 14. Field moisture data are shown for three soil layers (0 to 15, 0 to 45 and 0 to 105 cm). Included are values averaged for all nine monitoring times as well as those for the driest interval (July 15 to 17). Statistical differences among treatments were consistent throughout the five years of the study.

4.3.5.1 Field moisture. The most dramatic treatment differences in surface soil moisture occurred among peat applications where moisture content increased significantly averaging 9.6, 13.6 and 17.0 percent for the low, medium and high treatments, respectively. As well, soil moisture in the surface 0 to 15 cm was significantly higher in the 40 cm mixed treatment (13.8 percent) than in the 20 cm treatment (13.0 percent). There was also a significant interaction of mixing depth and peat application on surface moisture. Analysis of this interaction revealed that moisture increased with peat at both mixing depths, but for the 20 cm mixing depth the greatest increase was between the medium and high rates whereas the 40 cm treatment showed the greatest increase between the low and medium rates. Overburden application had no effect on surface moisture. Averages ranged from 13.0 to 13.7 percent.

Soil moisture in the 0 to 45 cm layer followed the same pattern as the 0 to 15 cm layer with respect to treatments. Moisture was significantly higher in the 40 cm mixed plots (15.2 percent) than in the 20 cm mixed plots (13.6 percent). Moisture content increased significantly with peat, averaging

Table 14. Soil moisture content (percent by volume) among treatments during the summer of 1989.

Sampling Depth (cm)	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Field Moisture									
Summer Average									
0 to 15	13.0^{a}	13.8^{b}	9.6^{a}	13.6^{b}	17.0^{c}	13.7^{a}	13.0^{a}	13.5^{a}	DP**
0 to 45	13.6^{a}	15.2^{b}	11.8^{a}	14.5^{b}	17.0^{c}	14.4^{a}	14.2^{a}	14.6^{a}	DP**
0 to 105	16.8^{a}	16.2^{a}	15.5^{a}	16.2^{a}	17.7^{a}	16.8^{a}	16.5^{a}	16.1^{a}	None
Driest Interval[1]									
0 to 15	5.9^{a}	5.4^{a}	3.8^{a}	5.8^{b}	7.4^{b}	5.7^{a}	5.2^{a}	6.2^{a}	None
0 to 45	9.1^{a}	10.6^{b}	7.6^{a}	10.0^{b}	12.0^{c}	9.7^{a}	9.7^{a}	10.1^{a}	None
0 to 105	14.6^{a}	13.6^{a}	14.5^{a}	14.1^{a}	13.7^{a}	13.4^{a}	13.8^{a}	15.1^{a}	None
Plant Available[2]									
Summer Average									
0 to 15	4.8^{a}	5.1^{a}	3.0^{a}	5.0^{b}	6.8^{c}	7.0^{c}	4.7^{b}	3.1^{a}	None
Driest Interval									
0 to 15	-2.3^{a}	-3.4^{a}	-2.8^{a}	-2.8^{a}	-2.8^{a}	-1.1^{b}	-3.1^{ab}	-4.2^{a}	None

Note: For each depth and factor, values followed by the same letter are not significantly different from each other at the 95% significance level. Summer average values are based on two measurements per plot and 9 time intervals including the driest interval. Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

[1] July 15 to 17, 1989 measurements.
[2] Plant available moisture = field moisture - moisture retained at 15 bar tension (measured in the lab).

** Probability less than 0.01.

11.8, 14.5, and 17.0 percent for the low, medium and high applications, respectively. The nature of the interaction of mixing depth and peat application was the same as that seen for surface moisture. Overburden application had no effect on soil moisture, averaging from 14.2 to 14.6 percent.

Soil moisture in the 0 to 105 cm profile averaged 16.5 percent. Moisture content tended to increase with peat application, as did the 0 to 15 cm and 0 to 45 cm layers. However, differences between treatments were all smaller (values ranging from 15.5 to 17.7 percent) and not statistically significant.

For the driest time interval monitored in 1989 (July 15 to 17), differences in field moisture among treatments generally followed the same trends as those for the summer average. Surface moisture (0 to 15 cm) averaged 5.7 percent during this period. The high and medium peat applications with 7.4 and 5.8 percent moisture, respectively, had significantly higher moisture than the low rate of application with 3.8 percent moisture (Table 14). Mixing depth and overburden application had no significant effect on moisture of the surface layer during the driest interval. Values for all treatments were the lowest recorded during the five years of monitoring.

Significantly higher moisture in the 0 to 45 cm layer was noted in 40 cm mixed plots (10.6 percent) compared to 20 cm mixed plots (9.1 percent) during the driest interval. This difference resulted from substantially higher moisture in the 15 to 45 cm layer of the deeper mixed plots (Figure 10). As well, moisture increased significantly with each peat application, but was not affected by overburden application.

There was no significant difference among treatments when considering the entire 0 to 105 cm profile for the driest interval. This indicates that treatments with lower moisture content in the upper (reconstructed) layers tended to have higher moisture content in the lower (sand) layers.

4.3.5.2 Plant available moisture. Differences in surface (0 to 15 cm) moisture available to plants among treatments are also presented in Table 14.

In this instance, the moisture content of the soil at wilting point (15 bar tension) is subtracted from the field moisture value. Results for the mean value, averaged for all nine time intervals, show that increasing peat content increased plant available moisture from 3.0 percent at the low to 6.8 percent at the high application rate. The increased moisture holding capacity of the peat more than compensated for its increased moisture retention (i.e., moisture unavailable to plants). However, with increasing overburden, moisture available to plants declined from 7.0 to 3.1 percent. However, these results may not accurately reflect the field situation where the clay overburden is distributed mainly in clods whereas samples prepared for retention analysis are ground to pass through a 2 mm sieve.

Results for plant available moisture in the 0 to 15 cm layer, during the driest period, indicated a deficit (negative value) for all treatments. The deficit was significantly greater in the high overburden than in the low overburden treatment. Increasing peat application had no effect on available moisture at this time.

4.4 HERBACEOUS COVER

Results of the two quantitative assessments of herbaceous cover are summarized in Table 15. Only species that had an overall average cover of 1 percent or more are shown. Agronomic invading species (i.e., those used in reclamation seed mixtures at Syncrude and Suncor in past years) contributed most of the cover in both 1986 and 1989. Sweet clover was easily the dominant species in 1986 with an overall cover of 37 percent. Hawksbeard, at only 1 percent cover, was the only species with 1 percent cover or more that had not been seeded in reclamation programs at Syncrude or Suncor. Alfalfa, wheatgrass and timothy were the other major species in 1986 with cover averaging 6, 4, and 2 percent, respectively. Total cover of all species averaged 53 percent. By 1989, species composition of the major invaders showed little change except that sow thistle replaced hawksbeard as the only non-agronomic species with more than 1 percent cover. The most noteworthy change in cover percentage was that sweet clover declined from 37 percent in 1986 to an average 10 percent in 1989. Cover of other species increased, but

Table 15. Percentage cover of the main invading herbaceous species in 1986 and 1989.

Species	Overall Cover	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
		20 cm	40 cm	Low	Med.	High	Low	Med.	High	
1986										
Sweet Clover	37	30^{a}	43^{b}	31^{a}	40^{b}	39^{b}	21^{a}	42^{b}	47^{b}	PO*
Alfalfa	6	7^{a}	6^{a}	5^{a}	7^{a}	7^{a}	5^{a}	6^{a}	8^{a}	None
Wheatgrass	4	3^{a}	4^{b}	1^{a}	3^{b}	7^{c}	4^{a}	3^{a}	4^{a}	DP**
Timothy	2	1^{a}	2^{b}	1^{a}	2^{b}	3^{c}	2^{a}	2^{a}	2^{a}	None
Hawksbeard	1	1^{a}	2^{a}	1^{a}	2^{a}	1^{a}	1^{a}	1^{a}	2^{b}	DPO*
Others	3	3^{a}	3^{a}	3^{a}	3^{a}	1^{a}	4^{a}	2^{a}	1^{a}	None
Total	53	45^{a}	60^{b}	41^{a}	56^{b}	60^{b}	37^{a}	56^{b}	64^{c}	PO**
1989										
Alfalfa	11	12^{a}	10^{a}	12^{a}	10^{a}	11^{a}	10^{a}	10^{a}	14^{a}	None
Sweet Clover	10	9^{a}	11^{a}	11^{a}	11^{a}	8^{a}	11^{a}	10^{a}	9^{a}	DP*
Timothy	4	3^{a}	4^{a}	2^{a}	4^{b}	5^{c}	3^{a}	4^{a}	4^{a}	None
Wheatgrass	4	2^{a}	5^{b}	3^{a}	4^{a}	4^{a}	2^{a}	3^{b}	6^{c}	None
Sow Thistle	4	4^{a}	3^{a}	1^{a}	3^{a}	6^{b}	3^{a}	3^{a}	4^{a}	DP**
Brome	1	1^{a}	1^{a}	1^{a}	1^{a}	2^{a}	1^{a}	1^{a}	1^{a}	None
Others	3	3^{a}	3^{a}	2^{a}	3^{a}	4^{a}	3^{a}	4^{a}	3^{a}	None
Total	36	35^{a}	37^{a}	32^{a}	36^{a}	40^{b}	33^{a}	35^{a}	41^{b}	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.

* Probability less than 0.05.
** Probability less than 0.01.

only slightly, so that total cover averaged 36 percent, approximately 17 percent less than in 1986.

Differences with respect to treatment were most pronounced in 1986, when cover was significantly greater on the deeper 40 cm mixed plots compared to the 20 cm mixed plots, and cover increased with application of peat and overburden. Sweet clover's dominance, in 1986 strongly influenced the pattern for total cover, but other species, namely wheatgrass and timothy, increased with reconstructed layer thickness and peat application, while hawksbeard increased with overburden application. In 1989, the trends among treatments were still evident (and statistically significant) for peat and overburden application, but there was no significant difference in cover between the two mixing depth treatments. Figures 13 and 14 illustrate the influence of peat and overburden application on vegetation cover. Sow thistle, timothy, and wheatgrass were the only species with statistically significant differences among treatments.

4.5 TREES AND SHRUBS

4.5.1 Survival

Survival of trees and shrubs in the fall of 1989 is shown in Table 16. Overall survival averaged 82.1 percent, ranging from a low of 54.5 percent in alder to 99.3 percent in white spruce.

Only one species, jack pine, showed a significant difference in survival between the two mixing depth treatments. In this case survival was 10 percent higher (73.6 versus 63.3) in the 40 cm treatment compared to the 20 cm treatment.

Two species, buffaloberry and alder, had significantly increasing survival with peat application. Both species had approximately 10 percent higher survival in the high application rate compared to the low rate. Although not statistically significant, several other species tended to have higher survival with increasing peat application. As a result, total survival was significantly higher in the high peat treatment. A significant interaction of mixing depth and peat application was indicated in four cases.

Figure 13. Sparse vegetation cover at year 5 on a plot that received a low application rate of peat and mineral overburden.

Figure 14. Dense vegetation cover at year 5 on a plot that received a high application rate of peat and mineral overburden.

Table 16. Percentage survival of trees and shrubs in the fall of 1989.

Species	Overall Survival	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
		20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Jack Pine	68.5	63.3^{a}	73.8^{b}	64.2^{a}	66.5^{a}	74.6^{a}	67.4^{a}	63.8^{a}	74.2^{a}	None
White Spruce	99.3	99.4^{a}	99.2^{a}	99.0^{a}	99.2^{a}	99.6^{a}	99.0^{a}	99.3^{a}	99.4^{a}	None
Serviceberry	90.5	90.0^{a}	91.0^{a}	91.0^{a}	90.3^{a}	90.3^{a}	89.9^{a}	90.6^{a}	91.1^{a}	None
Silverberry	90.3	91.5^{a}	89.0^{a}	87.6^{a}	89.7^{a}	93.5^{a}	95.7^{b}	91.1^{ba}	83.9^{a}	None
Buffaloberry	83.7	82.2^{a}	85.1^{a}	78.5^{a}	85.4^{b}	87.2^{b}	85.3^{a}	84.9^{a}	80.8^{a}	DP*
Pin Cherry	94.1	94.4^{a}	93.8^{a}	94.9^{a}	92.6^{a}	94.7^{a}	95.1^{a}	93.9^{a}	93.3^{a}	None
Rose	98.8	99.1^{a}	98.5^{a}	98.8^{a}	99.0^{a}	98.6^{a}	98.5^{a}	98.9^{a}	99.0^{a}	None
Poplar	78.3	80.9^{a}	75.7^{a}	74.9^{a}	74.6^{a}	85.6^{a}	88.2^{b}	84.9^{b}	62.1^{a}	None
Alder	54.5	52.9^{a}	56.1^{a}	49.4^{a}	51.4^{ab}	62.4^{b}	64.9^{b}	56.5^{b}	41.8^{a}	DP*
Willow	61.9	61.8^{a}	60.4^{a}	63.2^{a}	59.2^{a}	60.8^{a}	76.8^{b}	62.4^{b}	44.1^{a}	DP*
TOTAL	82.1	81.8^{a}	82.5^{a}	80.4^{a}	81.0^{a}	85.0^{b}	86.2^{c}	82.9^{b}	77.4^{a}	DP*

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level. Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

* Probability less than 0.05.

In each case, increasing survival with peat application was apparent only for the 20 cm mixing depth treatment but not the 40 cm treatment.

Survival of four species as well as total survival decreased significantly with overburden application. In most cases differences ranged from 25 to 30 percent greater survival on the low (i.e., no application) to the high application treatment.

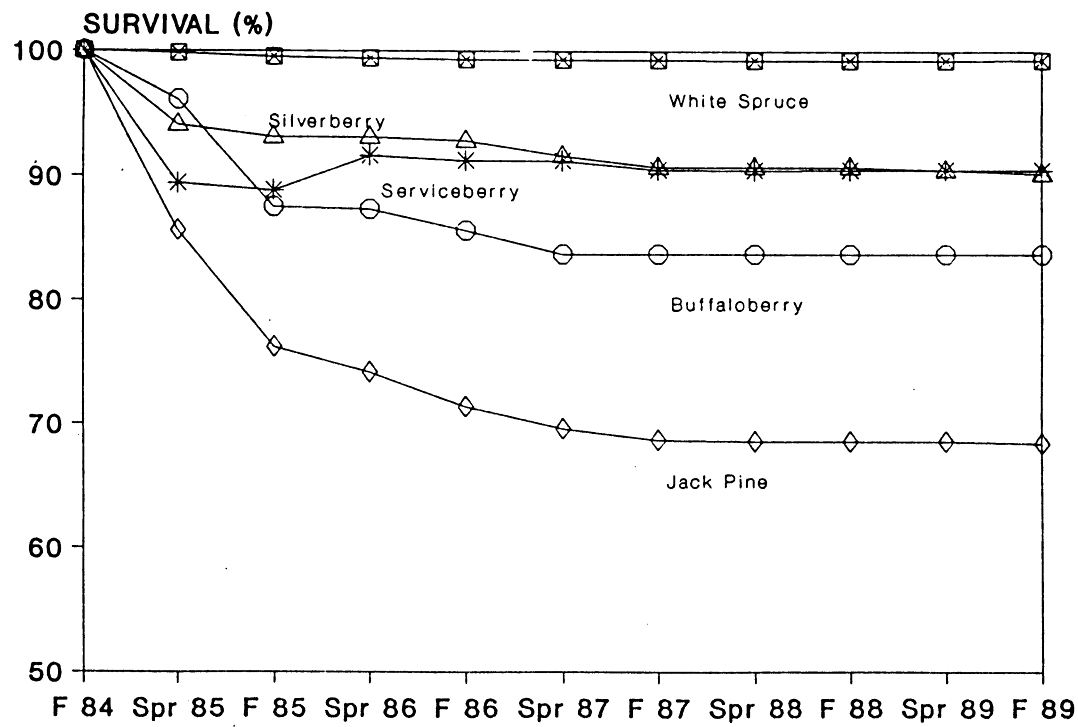
Changes in survival during the study are illustrated in Figure 15. Most of the mortality occurred during the first two years of the study and, with the exception of willow, survival remained constant over the last two years. The apparent increases in survival from fall 1985 to spring 1986 are a result of in-fill planting in three of the species.

4.5.2 Incidence of Disease, Insect, and Small Mammal Damage

With a few exceptions, disease, insect, and small mammal damage had a negligible effect on seedling health and survival. The most noteworthy effect was the extent of small mammal damage during the summers of 1987 and 1988. Occurrence during these years ranged from less than 1 percent (white spruce, jack pine, buffaloberry, and rose) to a maximum 20.2 percent (serviceberry 1987). Results are shown in Table 17 for those species with more than 1 percent overall occurrence.

In most cases damage was limited to a partial girdling of the stem for a 2 to 5 cm length. In contrast, many individuals of serviceberry and pin cherry were severed near ground level. However, most of these individuals had produced new shoots in subsequent surveys so that mortality due to small mammal damage was very low, estimated at a maximum of 1.5 percent in pin cherry.

Small mammal damage was closely related to treatment. Table 17 shows the results of the factorial ANOVA for the six species with more than 1 percent occurrence of small mammal damage. Most species showed strong trends of increasing mammal damage with increased mixing depth as well as with overburden application. Alder and pin cherry (1987 only) also had significantly greater damage on the high peat treatment compared to the low and medium treatments. The trends were very similar to total vegetation cover on the various treatments (Table 15) indicating that the small mammals



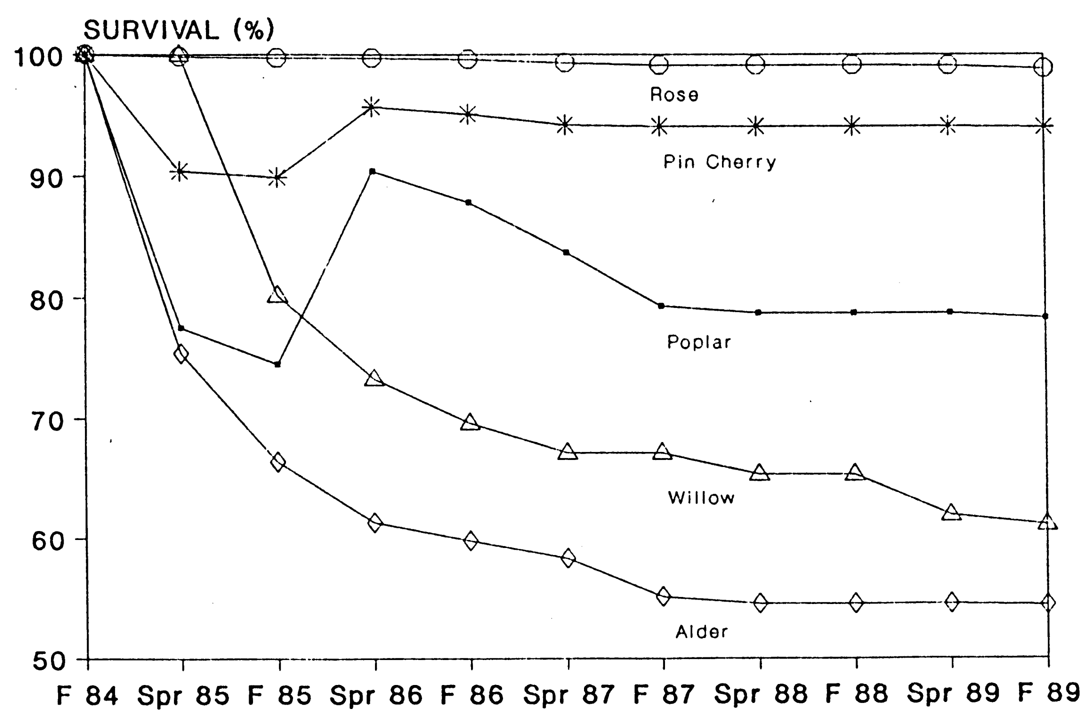


Figure 15. Tree and Shrub Survival From Fall 1984 to Fall 1989.

Table 17. Percentage occurrence of small mammal damage on trees and shrubs in 1987 and 1988.

Species	Overall	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant
		20 cm	40 cm	Low	Med.	High	Low	Med.	High	Interactions
1987										
Serviceberry	20.2	12.7^{a}	27.7^{b}	15.6^{a}	22.6^{a}	22.4^{a}	8.5^{a}	17.8^{b}	34.3^{c}	DO**
Silverberry	4.8	2.7^{a}	6.9^{a}	5.8^{a}	3.1^{a}	5.6^{a}	0.7^{a}	5.4^{a}	8.3^{a}	None
Pin Cherry	14.1	8.2^{a}	20.0^{b}	10.3^{a}	12.2^{a}	19.9^{b}	9.6^{a}	11.0^{a}	21.8^{b}	DP**, PO*
Poplar	9.2	3.9^{a}	14.5^{b}	7.4^{a}	10.4^{a}	9.9^{a}	1.8^{a}	9.3^{b}	16.5^{c}	DO**
Alder	2.9	1.4^{a}	4.4^{b}	0.3^{a}	2.2^{a}	6.3^{b}	1.1^{a}	2.9^{a}	4.7^{a}	DO*
Willow	3.4	2.2^{a}	4.5^{a}	2.2^{a}	4.6^{a}	3.3^{a}	1.8^{a}	4.2^{a}	4.2^{a}	None
1988										
Serviceberry	13.7	10.0^{a}	17.3^{b}	11.2^{a}	17.0^{a}	12.8^{a}	9.8^{a}	12.1^{a}	19.1^{b}	None
Silverberry	2.1	1.0^{a}	3.1^{a}	1.5^{a}	3.2^{a}	1.5^{a}	1.2^{a}	0.5^{a}	4.5^{a}	None
Pin Cherry	17.1	11.0^{a}	23.2^{b}	14.0^{a}	22.3^{a}	15.0^{a}	11.8^{a}	18.6^{a}	21.0^{a}	None
Poplar	5.3	3.5^{a}	7.1^{b}	4.2^{a}	7.1^{a}	4.7^{a}	2.4^{a}	2.5^{a}	11.1^{b}	DP*, DOP*
Alder	2.9	1.6^{a}	4.3^{b}	0.8^{a}	2.5^{ab}	5.5^{b}	1.0^{a}	2.0^{a}	5.8^{a}	None
Willow	7.8	4.6^{a}	10.9^{a}	4.2^{a}	9.6^{a}	9.6^{a}	6.6^{a}	6.6^{a}	10.1^{a}	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level. Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

* Probability less than 0.05.
** Probability less than 0.01

preferred the plots with the heavier vegetation cover.

In the first two years of the study small mammal damage was not observed while in the last year (1989) it occurred on less than 1 percent of any species.

4.5.3 Top Growth

4.5.3.1 Total height in fall 1989. Total height attained by trees and shrubs after five growing seasons on the site is summarized in Table 18.

Significant differences in the mean total height of all species combined (except willow) were noted between the two mixing depths and among peat and overburden application treatments. For the 20 cm mixing depth, mean height was 71.6 cm compared to 77 cm for the 40 cm depth. Among peat treatments mean height averaged 70.6 cm for the low treatment and increased to 77.8 cm for the high application. The mean total height of all species tended to decrease with overburden application, ranging from 81.5 to 68.7 cm.

When examined individually, all species except alder were taller in the 40 cm compared to the 20 cm mixed plots and in the case of six species (white spruce, serviceberry, buffaloberry, pin cherry, rose, and willow) these differences (approximately 4 to 10 cm) were statistically significant.

The height of the two coniferous species, jack pine and white spruce, increased significantly with peat application. Differences among these treatments were more substantial than between mixing depths with differences between low and high applications ranging from 20 cm (white spruce) to 25 cm (jack pine).

In several cases there was a significant interaction of mixing depth and peat application on total height. In each case the increase in height with peat application was most dramatic on the 20 cm mixing treatment compared to the 40 cm one.

Five species (jack pine, silverberry, buffaloberry, poplar, and alder) were significantly taller on the low overburden treatment compared to the high application. Differences between the low and high rates ranged from 5 to 9 cm in buffaloberry and jack pine, 25 cm for silverberry and poplar, and

Table 18. Total height (cm) of trees and shrubs in fall 1989.

Species	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Jack Pine	87.2[a]	94.9[a]	78.9[a]	89.9[b]	104.3[c]	99.5[b]	82.8[a]	90.8[ab]	None
White Spruce	66.1[a]	71.5[b]	57.5[a]	70.9[b]	78.0[c]	71.0[a]	67.0[a]	68.3[a]	DP**
Serviceberry	48.6[a]	52.1[b]	49.6[a]	52.5[a]	49.0[a]	51.0[a]	51.2[a]	48.9[a]	None
Silverberry	79.7[a]	88.0[a]	82.4[a]	81.2[a]	88.0[a]	97.5[b]	81.7[a]	72.5[a]	PO*
Buffaloberry	43.1[a]	48.4[b]	44.2[a]	44.9[a]	48.1[a]	47.5[b]	47.4[b]	42.3[a]	None
Pin Cherry	54.9[a]	64.8[b]	56.7[a]	59.2[a]	63.6[a]	62.2[a]	60.6[a]	56.7[a]	DP*, PO*
Rose	32.2[a]	40.1[b]	34.9[a]	37.9[a]	35.7[a]	35.4[a]	36.0[a]	37.2[a]	DP*
Poplar	125.8[a]	132.4[a]	126.9[a]	127.9[a]	132.6[a]	142.2[b]	128.6[ab]	116.5[a]	None
Alder	107.3[a]	101.1[a]	104.8[a]	107.3[a]	100.5[a]	126.8[c]	99.8[b]	86.0[a]	DO**, PO**
Willow	90.1[a]	99.4[b]	96.4[a]	99.7[a]	88.2[a]	96.1[a]	93.4[a]	N/A[1]	None
MEAN	71.6[a]	77.0[b]	70.6[a]	74.6[ab]	77.8[b]	81.5[b]	72.8[ab]	68.7[a]	DP*

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

[1]N/A: Due to low survival of willow in the high overburden treatment, data from these plots were omitted. Willow is not included in the mean.

* Probability less than 0.05
** Probability less than 0.01

40 cm for alder. Due to low survival of willow in the high overburden treatment, resulting in some plots with no survivors, the treatment was not tested for growth differences.

4.5.3.2 Annual height increment 1988 to 1989. Differences among treatments in the annual height increment (fall 1988 to 1989) of trees and shrubs are summarized in Table 19. For most species, including the two conifers, this was the year with the greatest annual increment. The average annual height increment of individual species ranged from less than 1 cm in serviceberry to more than 20 cm in jack pine, white spruce, poplar, and alder.

Mean height increment of all species combined (except willow) was 15.1 cm. Unlike previous years, mean height increment was not affected by mixing depth or peat application rates, but did decrease with overburden application. Mean height increment was significantly higher for the low overburden treatment (17.1 cm) compared to the medium (14.2 cm) and high (13.9 cm) treatments.

Figure 16 shows the height of each species on the 20 and 40 cm mixed plots from spring 1985 to fall 1989. In general, height increments were greatest during the summers of 1986, 1988, and 1989, as evidenced by steeper line slopes. These correspond to the growing seasons with the highest precipitation (Figure 9).

Alder was the only species influenced by mixing depth in 1989 (Table 19). Alder had significantly greater growth in plots mixed to 20 cm (28.3 cm) compared to plots mixed to 40 cm (22.3 cm). This contrasts with results from previous years in which most species had better annual growth on the 40 cm mixing treatment, hence the taller total height in 1989 of most species on this treatment (Figure 16). It is possible that the regular rainfall throughout most of the growing season provided adequate moisture without the need to exploit the lower reconstructed layer depth in the 40 cm treatment.

White spruce growth increment was significantly higher in the high (24.5 cm) and medium (23.7 cm) peat application treatments than in the low application (19.9 cm). This was the only species that had a significantly

Table 19. Annual height increment (cm) of trees and shrubs from fall 1988 to fall 1989.

Species	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Jack Pine	24.7^a	24.2^a	21.2^a	25.3^a	26.7^a	30.9^b	19.0^a	23.5^a	None
White Spruce	21.7^a	23.6^a	19.9^a	23.7^b	24.5^b	22.8^a	22.3^a	23.0^a	None
Serviceberry	0.3^a	1.4^a	0.9^a	2.3^a	-0.6^a	0.4^a	0.9^a	1.3^a	None
Silverberry	14.4^a	17.3^a	17.0^a	13.0^a	17.5^a	17.9^a	15.3^a	14.4^a	PO**
Buffaloberry	7.3^a	6.8^a	7.4^a	6.6^a	7.2^a	6.1^a	7.8^a	7.3^a	None
Pin Cherry	5.8^a	8.2^a	6.9^a	8.0^a	6.0^a	8.9^a	6.9^a	5.2^a	None
Rose	3.2^a	4.3^a	5.2^a	4.0^a	2.0^a	4.2^a	3.0^a	4.0^a	None
Poplar	29.3^a	28.2^a	33.2^a	24.6^a	28.4^a	32.3^a	28.1^a	25.8^a	None
Alder	28.3^b	22.3^a	25.7^a	27.5^a	22.7^a	30.3^b	24.5^a	21.2^a	DO**
Willow	15.5^a	16.3^a	19.6^a	13.7^a	14.4^a	16.8^a	14.9^a	N/A[1]	None
MEAN	15.0^a	15.1^a	15.2^a	15.0^a	15.0^a	17.1^b	14.2^a	13.9^a	PO*,DO**

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

[1]N/A: Due to low survival of willow in the high overburden treatment, data from these plots were omitted. Willow is not included in the mean.

* Probability less than 0.05
** Probability less than 0.01

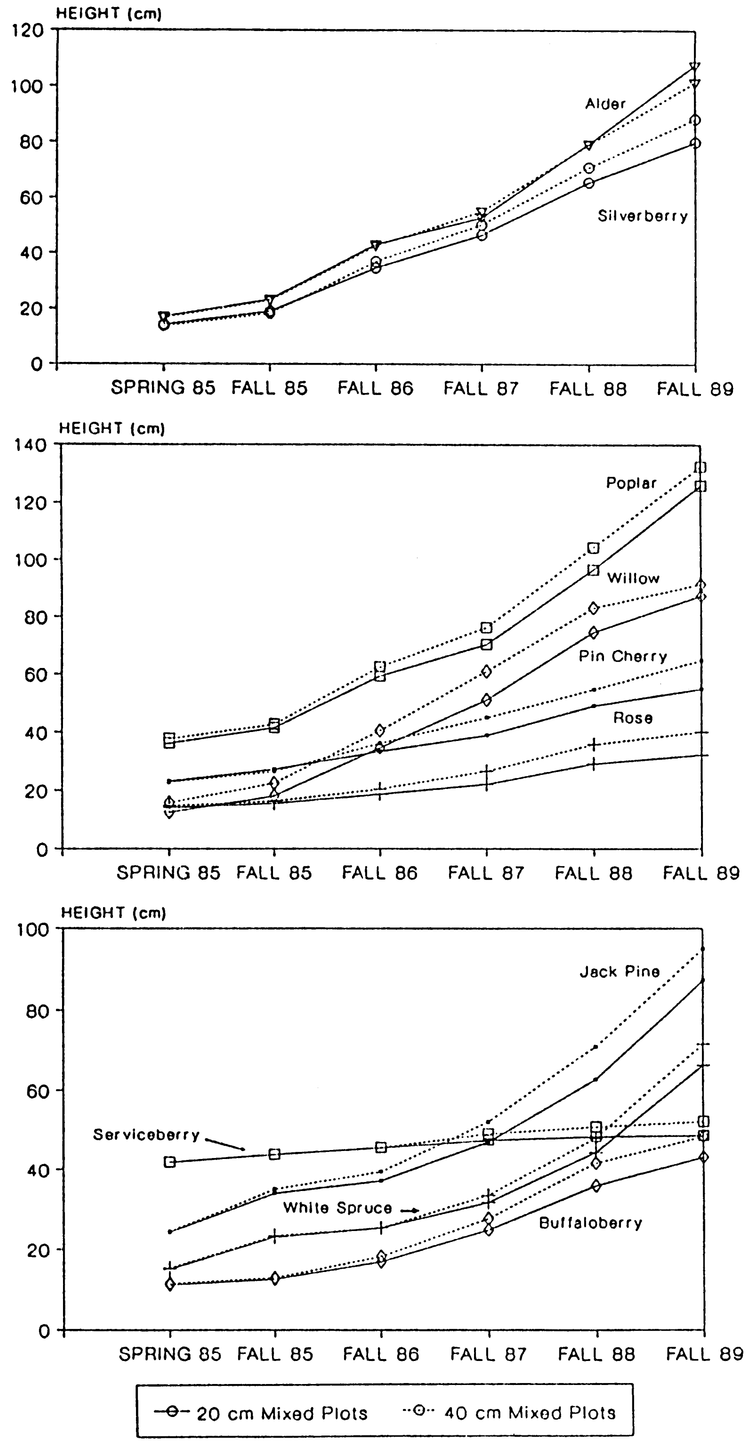


Figure 16. Tree and Shrub Height From Spring 1985 to Fall 1989.

greater growth rate with increasing peat application. In previous years this trend was significant for at least three species as well as for the overall mean.

Alder and jack pine had significantly higher growth in the low overburden application treatment compared to the medium and high applications. These trends were also observed in previous years, but with more species, including poplar, silverberry, buffaloberry, and willow.

4.5.3.3 Crown diameter in fall 1989. Variation in crown diameter among treatments after five growing seasons is shown in Table 20. In general, results were similar to those for total height. The only significant differences in the overall mean (excluding willow) occurred among the overburden treatments where crown diameter declined from 56.7 cm to 43.7 cm with increasing application.

Most species had a slightly greater diameter on the 40 cm mixing depth, but the difference was declared statistically significant for only two species (serviceberry and rose) averaging 3 to 5 cm wider on the deeper mixed plots. These differences were consistent throughout the study. The opposite was found for alder, where crown diameter was significantly wider in the 20 cm mixed plots (95.1 cm), compared to the 40 cm mixed plots (78.0 cm). The same trend was observed in 1988.

Significant increases in crown diameter with increasing peat application occurred only in the two coniferous species, a consistent result throughout the study. The magnitude of the difference between the low and high treatments was approximately 10 cm for these species.

The most noteworthy treatment effect on crown diameter was the negative influence of overburden application. In 1989, six species had significantly lower crown diameters with increasing overburden application and in previous years, serviceberry was the only species that never showed this trend. The magnitude of the difference between low and high levels of overburden application was much more than that between mixing depths or peat applications ranging from 7 to 12 cm for jack pine, buffaloberry, and pin cherry and from 22 to 40 cm for poplar, silverberry and alder.

Table 20. Crown diameter (cm) of trees and shrubs in fall 1989.

	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant
Species	20 cm	40 cm	Low	Med.	High	Low	Med.	High	Interactions
Jack Pine	52.1[a]	54.2[a]	48.9[a]	52.0[a]	58.6[b]	59.4[b]	47.6[a]	52.4[a]	None
White Spruce	35.1[a]	37.4[a]	29.4[a]	38.4[b]	40.9[b]	38.8[a]	35.3[a]	34.7[a]	DO*
Serviceberry	26.3[a]	29.5[b]	26.3[a]	28.9[a]	28.6[a]	27.3[a]	28.9[a]	27.5[a]	None
Silverberry	50.0[a]	49.3[a]	52.1[a]	49.3[a]	47.5[a]	62.1[b]	46.7[a]	40.1[a]	PO*
Buffaloberry	38.6[a]	44.2[a]	44.0[a]	39.1[a]	41.1[a]	47.1[b]	42.1[b]	35.0[b]	None
Pin Cherry	34.5[a]	37.4[a]	34.6[a]	34.8[a]	38.5[a]	39.7[b]	35.9[ab]	32.2[a]	None
Rose	28.0[a]	33.4[b]	31.4[a]	31.3[a]	29.6[a]	31.8[a]	30.3[a]	30.1[a]	DO*
Poplar	84.3[a]	85.6[a]	85.8[a]	85.5[a]	83.4[a]	96.7[b]	84.5[ab]	73.6[a]	None
Alder	95.1[b]	78.0[a]	91.4[a]	86.1[a]	82.1[a]	107.3[c]	84.5[b]	67.7[a]	DO**, PO**
Willow	31.6[a]	34.1[a]	33.8[a]	34.6[a]	30.2[a]	33.3[a]	32.4[a]	N/A[1]	None
MEAN	49.3[a]	49.9[a]	49.3[a]	49.5[a]	50.1[a]	56.7[c]	48.4[b]	43.7[a]	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

[1]N/A: Due to low survival of willow in the high overburden treatment, data from these plots were omitted. Willow is not included in the mean.

* Probability less than 0.05
** Probability less than 0.01

4.5.4 Rhizome Sprouting

Variation in silverberry, rose, and willow rhizome sprouting, based on an assessment in the summer of 1989, is given in Table 21. Values shown are a ratio of the number of rhizomes per parent plant surviving on each plot at the time of survey. Rhizome sprouting was most abundant in silverberry, followed by willow and rose, averaging approximately 6.9, 4.3 and 0.8 sprouts per plant, respectively.

Rhizome sprouting in silverberry decreased significantly with overburden application, averaging 10.7, 6.2, and 3.7 sprouts per plant for the low, medium, and high applications, respectively. There was no significant difference between mixing depths or among peat applications.

The number of rose rhizome sprouts increased significantly with mixing depth (0.6 versus 0.9) and peat application, averaging 0.5, 0.8, and 0.9 sprouts per plant for the low, medium, and high treatments, respectively. Differences among overburden treatments were inconsistent in that sprouting was significantly higher in areas with low overburden application compared to plots with medium application (0.9 versus 0.6), but plots with high overburden application (0.8) were not significantly different from either of these. Although statistically significant differences occurred among all treatments, the actual magnitude of these differences is very small (i.e., <1 sprout per parent).

The number of rhizome sprouts in willow decreased significantly with higher levels of peat and overburden application, but was not affected by mixing depth. The magnitude of the differences were similar for both peat and overburden in that the number of sprouts in the low rates (5.4 or 5.6) were twice those in the high (2.8).

4.5.5 Rooting

As described in Section 3.2.5.5, a detailed assessment of rooting parameters was conducted in the summer of 1989 in which measurements were taken of maximum root depth, root ball depth, maximum length of a major root, total root weight, and presence or absence of nodules. Emphasis will be

Table 21. Number of rhizome sprouts per parent plant in summer 1989.

Species	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Silverberry	6.9[a]	6.9[a]	7.3[a]	7.4[a]	5.9[a]	10.7[c]	6.2[b]	3.7[a]	None
Rose	0.6[a]	0.9[b]	0.5[a]	0.8[a]	0.9[b]	0.9[b]	0.6[a]	0.8[ab]	PO*
Willow	4.0[a]	4.5[a]	5.4[b]	4.6[ab]	2.8[a]	5.6[b]	4.3[ab]	2.8[a]	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots.

* Probability less than 0.05

placed on maximum root depth, maximum major root length, and root weight, because the measurement of root ball depth was somewhat subjective and therefore considered unreliable. All individuals excavated of the three nitrogen-fixing species (silverberry, buffaloberry, and alder) were well nodulated and therefore there was no apparent influence of treatment.

4.5.5.1 Maximum rooting depth. The maximum rooting depth of trees and shrubs after five growing seasons on the site is summarized in Table 22.

Maximum rooting depth, averaged for all treatments, ranged from approximately 17 cm in rose to 27 cm in poplar. Significant differences in maximum rooting depth between mixing depths were noted for five species (serviceberry, silverberry, buffaloberry, poplar, and alder), all of which had deeper roots in the 20 cm mixed plots compared to the 40 cm mixed plots. Differences between treatments ranged from 2 cm in serviceberry, silverberry, and buffaloberry to 4 to 6 cm in alder and poplar, respectively.

Peat application rate had little influence on maximum rooting depth. In two species, buffaloberry and poplar, maximum rooting depth was significantly deeper in medium peat application plots (20.9 and 32.1 cm, respectively) compared to other peat treatments (averaging 17.4 and 24.7 cm, respectively.

A significant influence of overburden application on rooting depth was only evident for two species, alder and poplar. In both species rooting depth decreased with overburden application, differing up to 5 cm between treatments. The rooting depth of several other species also tended to decrease with application, but the trend was not statistically significant. These differences probably reflect the larger trees and shrubs on the low overburden treatment.

In addition to the main treatment effects noted, there were several significant interactions among treatments including five three-way interactions of all treatments. Results such as these are an indication that rooting patterns among treatments are complex and that variation in rooting depth cannot be attributed to levels of any one factor (i.e., mixing depth, peat, or overburden) without consideration of the levels of the other factors.

Table 22. Maximum rooting depth (cm) of trees and shrubs in summer 1989.

Species	Mixing Depth (D)		Peat Application (P)			Overburden Applicatiion (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Jack Pine	22.5^{a}	22.2^{a}	21.2^{a}	23.3^{a}	22.5^{a}	23.6^{a}	22.9^{a}	20.5^{a}	DPO**
White Spruce	21.2^{a}	22.0^{a}	20.6^{a}	23.8^{a}	20.5^{a}	23.6^{a}	21.4^{a}	19.9^{a}	DPO*
Serviceberry	19.3^{a}	17.1^{a}	18.0^{a}	18.6^{a}	18.0^{a}	17.6^{a}	18.6^{a}	18.3^{a}	None
Silverberry	20.0^{b}	18.2^{a}	18.5^{a}	19.6^{a}	19.2^{a}	20.2^{a}	19.3^{a}	17.9^{a}	None
Buffaloberry	19.7^{b}	17.5^{a}	18.5^{ab}	20.9^{b}	16.3^{a}	19.0^{a}	18.4^{a}	18.3^{a}	DP*, DPO**
Pin Cherry	19.0^{a}	19.0^{a}	17.9^{a}	21.2^{a}	17.8^{a}	19.4^{a}	17.8^{a}	19.8^{a}	DO*
Rose	16.8^{a}	17.5^{a}	16.5^{a}	19.0^{a}	16.0^{a}	18.0^{a}	17.9^{a}	15.7^{a}	DO**, DPO*
Poplar	29.9^{b}	24.4^{a}	26.1^{a}	32.1^{b}	23.3^{a}	28.7^{b}	29.1^{b}	23.7^{a}	DP**, DPO*
Alder	26.2^{b}	22.7^{a}	24.4^{a}	25.0^{a}	24.0^{a}	27.5^{b}	23.6^{ab}	22.2^{a}	DP*, DO*
Willow	19.8^{a}	21.0^{a}	21.1^{a}	20.5^{a}	19.6^{a}	22.0^{a}	20.6^{a}	18.6^{a}	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots. Plot means were based on 5 individuals per species.

* Probability less than 0.05.
** Probability less than 0.01.

4.5.5.2 Maximum length of a major root. The maximum length of a major root of the trees and shrubs is shown in Table 23.

Maximum length ranged from approximately 6 cm in serviceberry to an average 208 cm in poplar. In general, major roots in the 20 cm mixed plots were longer than the 40 cm plots, and in three species - silverberry, alder, and willow - the difference was statistically significant. Root length in these species averaged 88, 92, and 74 cm, respectively.

Significant differences in root length with peat application were found for jack pine and willow. However trends were inconsistent. Maximum root length in jack pine was highest in the medium peat application (65 cm) compared to other applications (averaging 42 cm). Willow maximum root length was greater in the low application plots (76 cm), compared to the medium plots (52 cm).

Maximum root length decreased significantly with overburden application in white spruce, jack pine, and alder, with differences between low and high applications ranging from 20 cm for white spruce and jack pine to 50 cm for alder. In contrast, root length in pin cherry was significantly higher in high overburden application plots (55 cm), compared to the medium treatment plots (34 cm).

4.5.5.3 Total root weight. The total root weight of five year old trees and shrubs is summarized in Table 24.

Mean total root weight ranged from approximately 12 g in rose to an average of 100 g in alder. Four species, silverberry, buffaloberry, poplar, and willow, had greater root weight in the 20 cm mixing depth treatment compared to the 40 cm treatment, with the difference ranging from 5 to 30 g between treatments. Conversely in white spruce, root weight was significantly higher in the 40 cm mixed plots (28.4 g) compared to the 20 cm mixed plots (19.6 g).

The root weight of only one species, jack pine, differed significantly with peat application. Here root weight was lower in the low application averaging 27.6 g, compared to 53.6 and 50.3 g for the medium and high application rates.

Table 23. Maximum length (cm) of a major root of trees and shrubs in summer 1989.

Species	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Jack Pine	49.1[a]	48.8[a]	40.9[a]	64.8[a]	41.1[a]	61.1[b]	47.4[ab]	38.3[a]	None
White Spruce	44.8[a]	48.5[a]	40.7[a]	55.2[a]	44.0[a]	58.9[b]	41.4[a]	39.6[a]	DP*
Serviceberry	6.4[a]	5.9[a]	6.8[a]	5.0[a]	6.6[a]	6.6[a]	5.2[a]	6.6[a]	DPO**
Silverberry	87.6[b]	52.2[a]	87.5[a]	50.3[a]	71.9[a]	75.4[a]	82.1[a]	52.1[a]	DP*
Buffaloberry	39.4[a]	41.1[a]	43.6[a]	38.1[a]	39.0[a]	35.9[a]	42.7[a]	42.1[a]	DP**
Pin Cherry	45.5[a]	45.4[a]	41.5[a]	51.5[a]	43.4[a]	47.6[ab]	33.5[a]	55.2[b]	DPO*
Rose	46.4[a]	38.0[a]	36.8[a]	36.4[a]	53.4[a]	49.0[a]	36.7[a]	40.9[a]	None
Poplar	231.6[a]	184.1[a]	208.7[a]	223.9[a]	191.0[a]	246.5[a]	212.8[a]	164.3[a]	None
Alder	91.7[b]	60.6[a]	72.7[a]	82.1[a]	73.8[a]	108.9[b]	63.5[a]	56.2[a]	DO**
Willow	73.8[b]	52.4[a]	76.4[b]	51.9[a]	61.0[ab]	63.9[a]	65.2[a]	60.3[a]	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots. Plot means were based on 5 individuals per species.

* Probability less than 0.05.
** Probability less than 0.01.

Table 24. Total root weight (g) of trees and shrubs in summer 1989.

Species	Mixing Depth (D)		Peat Application (P)			Overburden Application (O)			Significant Interactions
	20 cm	40 cm	Low	Med.	High	Low	Med.	High	
Jack Pine	41.9[a]	45.8[a]	27.6[a]	53.6[b]	50.3[b]	52.6[b]	57.4[b]	21.6[a]	None
White Spruce	19.6[a]	28.4[b]	21.1[a]	27.7[a]	23.3[a]	26.0[a]	24.4[a]	21.7[a]	None
Serviceberry	16.3[a]	14.0[a]	16.0[a]	13.4[a]	16.2[a]	15.3[a]	15.4[a]	14.8[a]	DPO*
Silverberry	40.4[b]	22.2[a]	32.4[a]	23.6[a]	37.8[a]	28.7[ab]	46.2[b]	18.9[a]	DP**, DPO**
Buffaloberry	14.7[b]	10.3[a]	14.5[a]	12.2[a]	10.7[a]	11.1[a]	15.8[a]	10.5[a]	DP*
Pin Cherry	22.1[a]	14.0[a]	14.1[a]	13.8[a]	26.2[a]	15.4[a]	22.8[a]	15.9[a]	None
Rose	12.2[a]	11.4[a]	13.4[a]	9.6[a]	12.4[a]	11.8[a]	12.5[a]	11.1[a]	None
Poplar	79.8[b]	49.5[a]	67.4[a]	48.5[a]	78.0[a]	67.7[b]	91.1[b]	35.1[a]	None
Alder	113.8[a]	86.0[a]	113.6[a]	86.4[a]	99.5[a]	148.9[b]	85.9[a]	64.8[a]	None
Willow	17.5[b]	11.9[a]	16.7[a]	11.6[a]	15.9[a]	16.4[a]	15.9[a]	11.9[a]	None

Note: For each species and factor, values followed by the same letter are not significantly different from each other at the 95% significance level.
Values for mixing depth are the mean of 27 plots, whereas those for peat and overburden are the mean of 18 plots. Plot means were based on 5 individuals per species.

* Probability less than 0.05.
** Probability less than 0.01.

Four species (jack pine, silverberry, poplar, and alder) had significantly lower total root weight in high overburden areas than other application levels. Differences between treatment rates ranged from approximately 27 g in silverberry to 84 g in alder.

5. DISCUSSION

5.1 EFFECTIVENESS OF PLOT CONSTRUCTION METHODOLOGY IN ACHIEVING TARGET RECONSTRUCTED SOIL SPECIFICATIONS

The methods used for plot construction were successful in terms of providing distinct treatments varying in depth, organic C, and clay content in the reconstructed soils. However, refinements are necessary to increase the accuracy in achieving target organic C and especially clay contents. The greatest source of error is probably the assumptions used in the equations to determine the reconstructed soil concentrations. These equations have to be modified to account for:

1. Clay content of the tailings sand;
2. Clay and sand content of the peat;
3. The bulk density of the peat after spreading (and subsequent compaction) prior to mixing.

The third modification could be overcome by premixing the components in a batch process but this is probably not an operationally feasible procedure.

The sticky clay overburden also presented problems with respect to even placement and thorough mixing. The requirement of evenly spreading a 2.2 cm layer of this material was unrealistic using conventional (i.e., operational scale) equipment, as was thorough mixing without pre-drying and pulverizing the material. Consequently, the resulting soil mixtures were homogeneous with respect to the peat and sand components, but the clayey overburden was distributed as clods within the peat/sand matrix. This resulted in difficulties during planting and probably had a detrimental effect on moisture supply to the vegetation, as opposed to the more desirable condition where the clay particles are distributed throughout the reconstructed layer. These technical problems have to be solved before application of this material can be effective.

Apart from the difficulty in mixing the overburden material, the Rotoclear machine was highly effective in mixing the other components and in providing accurate depth control. However, a relatively high cost of operation and difficulties on steeply sloping terrain have limited its use in the oil sands to the two years when the plots were constructed.

5.2 INFLUENCE OF AMENDMENTS ON SOIL PHYSICAL AND CHEMICAL PROPERTIES OF THE RECONSTRUCTED SOIL

Apart from the intended differences in thickness, organic C, and clay content among treatments, there was relatively minor variability in most soil properties. In several instances where statistically significant differences were detected, such as with pH and electrical conductivity, the magnitude of these differences was probably negligible in terms of their influence on plant growth. One possible exception was nitrogen status, which increased with peat application in both total and plant available (NO_3-N) quantities. Since most plots had very low available N, often averaging 1 ppm or less, it is possible that nitrogen supply could have limited growth in some instances, especially in plots with the low peat application.

An interesting observation noted very early in the study was the evidence of salt leaching within the reconstructed profile as evidenced by lower electrical conductivity and the presence of sulphate in the upper (0 to 20 cm) compared to the lower (20 to 40 cm) reconstructed soil. However, based on soil data collected in reclaimed areas on the Suncor Lease (Hardy BBT Limited 1989), the other properties assessed in this study appear to remain stable for at least 10 years after the time of soil reconstruction.

The importance of the reconstructed layer is evident considering the sandy texture and extremely low nutrient status of the tailing sand prior to amendment. It is interesting to note that application of amendments produced a reconstructed soil that would be rated as "poor suitability" for reclamation based on the criteria in Soil Quality Criteria Working Group (1987). The major limiting factor is texture, ranging from sand to loamy sand.

5.3 INFLUENCE OF AMENDMENTS ON SOIL MOISTURE

There was an apparent anomaly between laboratory analytical results of soil moisture retention and field measurements taken throughout the study.

According to the laboratory results, increasing either peat or overburden application from low to high led to an almost identical increase in moisture retention of the reconstructed soil. However, field measurements indicated that peat application led to increased moisture, but that overburden application had no effect. The reason for this apparent discrepancy is attributed to the distribution of the clay as clods in the field plots as opposed to the ground and mixed laboratory samples.

In the case of peat application, the results indicated that the increased field moisture among treatments more than compensated for the extra moisture retained by the peat (i.e., unavailable moisture). However, in the case of overburden application, the greater moisture retention of the clay led to significantly lower quantities of plant available moisture, resulting in a moisture deficit during dry periods of the growing season. This deficit was most pronounced in plots with the high overburden application. It is important to qualify this statement because it is not known what influence the cloddy distribution of the clayey overburden had on plant available moisture.

The distribution of moisture throughout the profile to a depth of 105 cm clearly demonstrates the effectiveness of the reconstructed soil in retaining surface moisture (i.e., upper 30 cm zone). For this reason plots with the deeper 40 cm reconstructed soil retained more moisture in this zone than those with 20 cm soil followed by 20 cm of tailings sand. This increased moisture probably accounts for the better growth of most species (trees, shrubs and other herbaceous plants) on the 40 cm mixed plots than on the 20 cm plots. The advantages of the thicker reconstructed layer was most apparent during periods of drought, when moisture in the surface 15 cm layer was near permanent wilting point. During these periods, plots with the 40 cm reconstructed soil layer had substantially more moisture in the 15 to 30 cm and 30 to 45 cm intervals than the plots with the 20 cm soil layer. The extra moisture would become even more important with time, as the trees and shrubs grow, and place more demand on soil moisture supply.

5.4 INFLUENCE OF AMENDMENTS ON ESTABLISHMENT OF AN INITIAL GROUND COVER

All factors under study had an effect on the establishment of an initial ground cover, especially during the first two years of the study. Based on the detailed assessment carried out during the second growing season, ground cover increased substantially with peat and overburden application as well as with thickness of the reconstructed soil. At this stage of the study, overall ground cover was dominated by sweet clover. This species reproduces exclusively by seeds which have limited wind dispersal and must be scarified before germination (Turkington et al. 1978). These properties suggest that the species was introduced with the peat and its abundance may be attributed to the scarification provided by the Rotoclear machine during mixing. The benefit of increased mixing depth and peat application to initial ground cover can be attributed to a combination of the greater number of seeds introduced with the peat as well as superior moisture conditions for germination and growth.

The reason for the effect of overburden application is unclear, especially since most of the planted species had poorer survival and/or growth with increasing overburden. One possibility is that the clayey overburden reduced the rate of infiltration, providing more favourable conditions for seed germination, after which the high drought tolerance of sweet clover (Turkington et al. 1978) allowed for good growth in all plots.

By the fifth growing season differences in vegetative cover still existed among treatments but were less evident. In particular, mixing depth generally had no effect. The greater precipitation in the last two years may have tended to mask the treatment differences observed during the first survey.

It should be noted that due to the near level topography of the study plots, surface erosion was not a problem on any of the treatments. However, the minimal ground cover on some plots, especially those with the low peat and overburden applications, probably contributed to damage from wind and windblown sand observed on several of the planted seedlings during the first two years. Jack pine appeared to be the most sensitive to this type of damage.

5.5 INFLUENCE OF TREATMENT ON TREE AND SHRUB SURVIVAL AND HEALTH

Overall survival was very good for most of the species tested. In particular, five of the species, with an overall average of 90 percent or greater survival after five years, appear to be especially well suited to reclaimed tailings sand. These include: white spruce, rose, pin cherry, serviceberry and silverberry. With the exception of a negative influence of overburden application on silverberry, survival of these species was unrelated to treatment.

Poplar, alder and willow were also highly sensitive to increasing overburden application, while buffaloberry and alder had better survival with peat application. For these species, factors that varied among treatments that probably contributed to survival differences include:

1. Protection by herbaceous cover.
2. Competition for moisture with herbaceous cover.
3. Variation in plant available moisture among mixtures.
4. Damage to plants during planting in heavy clay soils.
5. Poor root penetration in heavy clay soils.
6. Damage caused by small mammals.

Jack pine had better survival on the deeper mixing depth plots and survival also tended to increase with peat and overburden application. For this species, survival appears to be well correlated with ground cover which suggests protection from the wind is the reason for enhanced survival.

The impact of vegetation cover on survival of planted trees and shrubs has been variable in the Oil Sands Region as well as the Eastern Slopes Region. Operational planting at Suncor of a variety of species has shown a large amount of variability over the years (Suncor 1983). However, survival has generally averaged 50 to 70 percent three to four years after planting in sparsely vegetated areas, compared to only 10 percent in densely vegetated areas. Much of the mortality was attributed to small mammals. One exception was white spruce which survived as well or better under dense herbaceous cover.

Five year survival of lodgepole pine and white spruce was unaffected when planted among two mixtures of grasses and legumes sown at various rates in Southern and Central Alberta (King 1985). Conversely, survival of several trees and shrubs (including lodgepole pine, white spruce, willow and balsam poplar) planted at Smoky River Coal Ltd. near Grande Cache, Alberta was much higher when planted in areas seeded to grasses and legumes (Macyk 1985). The superior survival was attributed to the protection afforded the seedlings by the vegetation cover, especially trapping snow in winter, which far outweighed the competition effect during the growing season. In this same study it was noted that seedlings grown in association with legumes (alfalfa) appeared more vigorous than those grown with grasses.

Based on the results of these studies it is clear that the effect of an associated ground cover on seedling survival is dependent on many factors. It is probable that the species composition of the ground cover plays an important role, with grasses providing a much more competitive environment than a cover dominated by legumes and other herbaceous species.

5.6 INFLUENCE OF TREATMENT ON TREE AND SHRUB GROWTH

5.6.1 Top Growth

The general trends indicated in this study, regarding the influence of treatment on top growth, include a beneficial effect of mixing depth and peat application, but a detrimental effect of overburden application. It is important however, to note that these effects were not consistent for all species.

In terms of the magnitude of the differences in total height among treatments, the detrimental effects of overburden were the most dramatic and statistical significance occurred in five of the species. The two tallest species, poplar and alder, averaged 25 cm and 40 cm taller, respectively, on the low overburden treatment than on the high treatment. These values represent approximately 25 and 40 percent, respectively, better growth on the low treatments. The other three species (jack pine, silverberry and buffaloberry) ranged from 5 to 15 cm taller (10 to 35 percent) on the low application treatment.

Only the two conifers exhibited substantial (and statistically significant) increases in total height in response to increasing peat application. Trees on the high application plots averaged 25 cm and 20 cm taller than those on the low application for jack pine and white spruce, respectively. Based on the actual tree heights, these differences represent approximately 30 percent more growth on the high application plots.

Six of the ten species had significantly better growth on the thicker (40 cm reconstructed layer) plots than those mixed to 20 cm. The magnitude of the difference however, was generally much less than was noted among peat and overburden application rates. For example, differences between the two treatments ranged from less than 4 cm to a maximum 10 cm more growth on the deeper plots. In almost all cases the difference represented 10 percent better growth on the deeper mixing depth.

Information on juvenile stand development (under 20 years of age) is scarce for comparison with results presented in this study. However, some data on white spruce are available for the Lac La Biche and Whitecourt Forests from the Alberta Forest Service "Stand Dynamics After Harvesting" research project (Fochlar and Mah 1987). Five year growth of seedlings planted into a total of 22 plots ranged from 15 to 50 cm. These were lower than the averages obtained for all 18 treatments in this study which ranged from 50 to 89 cm.

Juvenile stand development data for lodgepole pine and spruce (white and Engelmann) have also been reported in W.R. Dempster and Associates Ltd. (1988). Growth data were collected from cut-over or burned stands in west-central Alberta. Total height of comparably aged trees (i.e., 6 years old) were 138 cm for the pine and 63 cm for the spruce. Compared to this study, the pine growth was better than all 18 treatments (maximum of 113 cm for the high peat and low overburden applications), whereas the spruce growth was comparable to the treatment with medium peat application rates and 20 cm mixing depth, or the low peat application rate at 40 cm mixing depth.

5.6.2 Root Growth

The most noteworthy trend among parameters measured on root growth was a tendency towards larger root systems associated with deciduous species on the 20 cm mixed plots than on the 40 cm plots. This is opposite to the trend for top growth. Furthermore, maximum rooting depth was almost always contained within the upper 20 cm, irrespective of mixing depth. The results indicate that these species tend to allocate more of their resources to root growth when growing in a limiting (moisture and/or nutrients) substrate.

The conifers showed little relationship with mixing depth. It should be noted that these species, as well as serviceberry, buffaloberry, pin cherry, and rose, had relatively little root growth beyond the extent of the original container plug. It is suggested that several more years of growth are required in this environment before more definitive differences in rooting patterns can be detected.

6. CONCLUSIONS

1. The methods used for plot construction are effective in achieving distinct levels of mixing depth, organic C and clay content, but changes to the amendment calculations are necessary to meet specific organic C and clay concentrations in the reconstructed soil.
2. Spreading and rotovating clayey overburden is ineffective for achieving a uniform distribution of clay particles in the reconstructed soil.
3. Organic C content, total N, and S increase with peat application while total P and K increase with overburden application.
4. Plant available nitrogen increases with peat application, while potassium increases with peat and overburden application.
5. The chemical composition of the reconstructed soil in the 40 cm mixed plots is relatively uniform except for evidence of some sulphate salt migration from the 0 to 20 cm layer into the 20 to 40 cm layer.
6. Nutrient status in the tailings sand below the reconstructed layer is very low compared to reconstructed soils.
7. Water table elevations, which averaged 200 cm below the surface, can change by as much as 50 cm in response to rainfall.
8. In the 40 cm mixed plots, moisture content is greatest in the surface (0 to 45 cm) layers, whereas in 20 cm mixed plots moisture is highest in the lower (75 to 105 cm).
9. Soil moisture content increases substantially with peat application but is not influenced by overburden. After accounting for moisture retention characteristics of the amendment materials (peat and overburden), plant available moisture increases with peat addition, but decreases considerably with overburden application. As a result, moisture deficits that usually occur in the surface layer of all treatments in July or August are smallest in the low overburden application and greatest in the high overburden application.

Treatment has a negligible effect on total moisture content in the 0 to 105 cm interval.

10. Herbaceous cover increases substantially with peat and overburden application. Agronomic invading species, seeded in adjacent reclamation areas, contribute most of the cover.
11. Fifth year survival of most trees and shrubs was slightly higher with increased peat application but lower with overburden application. Species with the highest survival, at 90 percent or higher, include white spruce, rose, pin cherry, serviceberry and silverberry. Alder had the lowest survival at 55 percent.
12. Factors such as disease, insect and small mammal damage have a very minor impact on overall survival and growth.
13. Top growth of most species was reduced with increasing overburden application, and was greater on plots mixed to 40 cm than to 20 cm. Conifer growth increased with peat application. Peat and overburden application had a greater effect on growth than did mixing depth. Differences among treatments are attributed to differences in moisture supply.
14. Sprouting rate of three species averaged 6.9 sprouts per plant for silverberry, 4.3 for willow and 0.8 for rose. Sprouting rate generally decreased with peat and overburden application, an opposite trend to that observed for herbaceous vegetation cover.
15. Total root weight, maximum root depth and major root length tended to decrease with increased mixing depth, opposite to what was observed for top growth. These parameters tended to decrease with increasing overburden application but were not affected by peat application.
16. Mixing depth had no effect on rooting depth for most species during the first 5 years.

7. RECOMMENDATIONS

1. The study plots were destroyed by construction activities on the Syncrude site soon after data collection in 1989. Consequently, recommendations are based on a very short research time frame.
2. The use of heavy clayey material as an amendment to tailings sand should be avoided until a technological solution is found to effectively mix these materials.
3. Application of peat to tailings sand greatly enhances physical and chemical properties of the reconstructed soil as well as improving plant establishment and growth. Maximum benefits are observed at the highest application rate (4 percent organic C). Therefore, this high rate is recommended to achieve the best seedling performance, especially for conifers, as well as to increase invasion of other non-planted species.
4. The thicker application depth (40 cm versus 20 cm) tends to increase plant growth and the rate of species invasion, but to a lesser extent than does peat application. The benefit of a thicker mixed layer may increase as the seedlings grow and place more demands on the soil. The thicker depth is therefore recommended if optimum growth is desired.
5. A lack of relevant data on juvenile stand development makes it difficult to compare seedling performance on the various mixtures to what might occur on the natural soils in the area. Data such as these are necessary before recommendations can be made regarding which mixtures provide "at least equal or better capability" than the natural soils. Future studies should include plantings in surrounding natural environments so that these comparisons can be made within a reasonable (i.e., less than 20 years) period of time.
6. Since peat excavated for reclamation tends to have a substantial mineral component, application of this material as a cap without incorporation into the sand may provide at least as much benefit. This method is currently being investigated at Suncor.

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APPENDIX A

SOIL ANALYTICAL METHODS

Analysis	Method	Reference
pH and E.C.	1:1 Soil: Water Suspension	McKeague (1978) Methods 3.13, 3.22
Available N, S	$CaCl_2$ extraction Colorimetric determination	McKeague (1978) Method 4.48
Available P, K	$NaHCO_3$ extraction Colorimetric-P, Flame Emission-K	McKeague (1978) Methods 4.41, 4.52
Organic Carbon	Dry Combustion/Titration	McKeague (1978) Method 3.614
Total N	Kjeldahl	McKeague (1978) Method 3.623
Total S	Alkaline Oxidation	McKeague (1978) Method 3.633
Total P and K	$HNO_3/HClO_4/HF$ digestion, IPC atomic emission	McKeague (1978) Method 3.64
Moisture Retention	Pressure plate extraction	McKeauge (1978) Method 2.43
Particle Size Analysis	Pipet method	McKeague (1978) Method 2.11
Bulk Density (surface)	Core method	McKeague (1978) Method 2.21

APPENDIX B

SELECTED STATISTICALLY SIGNIFICANT INTERACTIONS FOR RECONSTRUCTED SOIL PROPERTIES

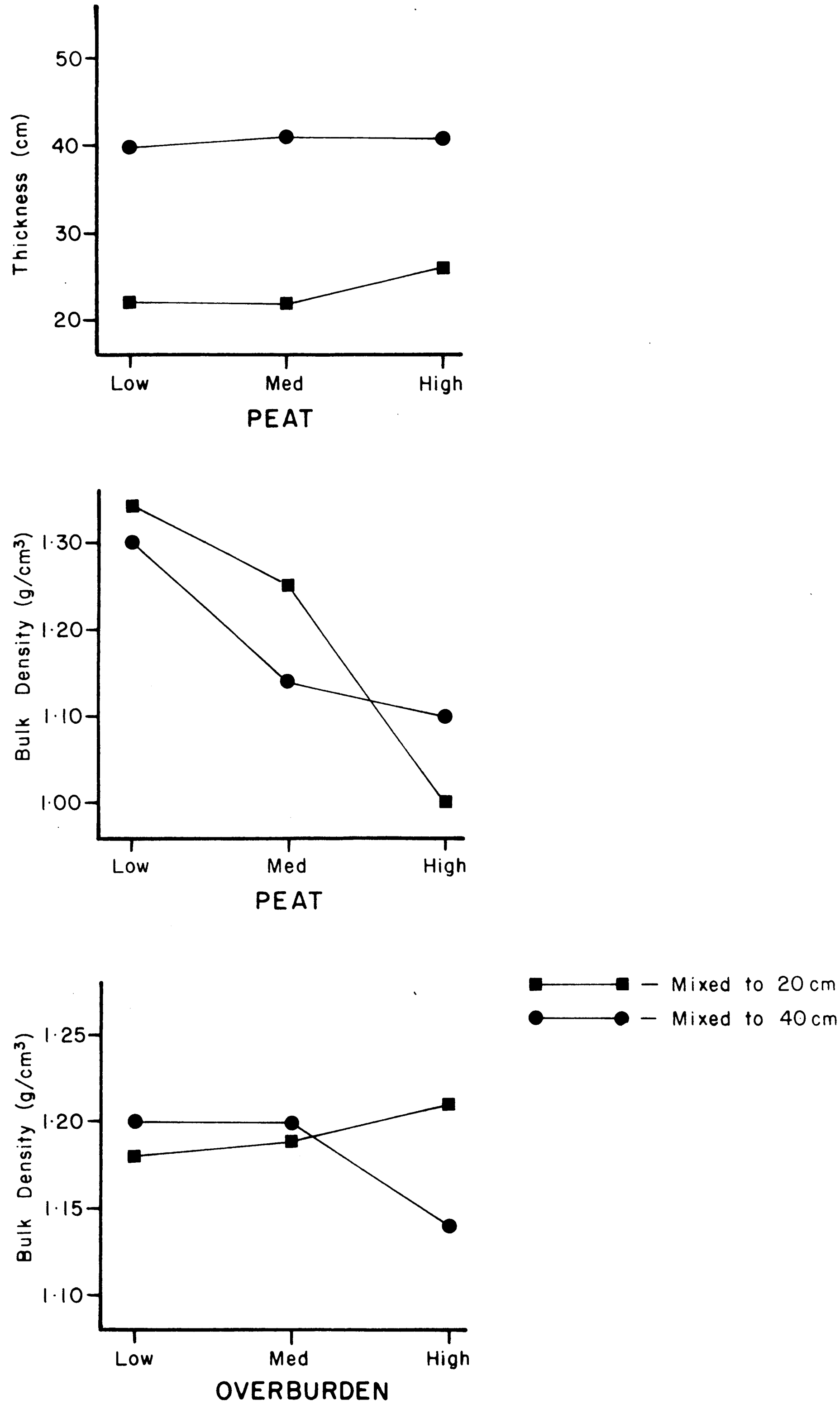

Figure B1. Significant Two-way Interactions for Thickness and Bulk Density of the 0 to 20 cm Reconstructed Layer.

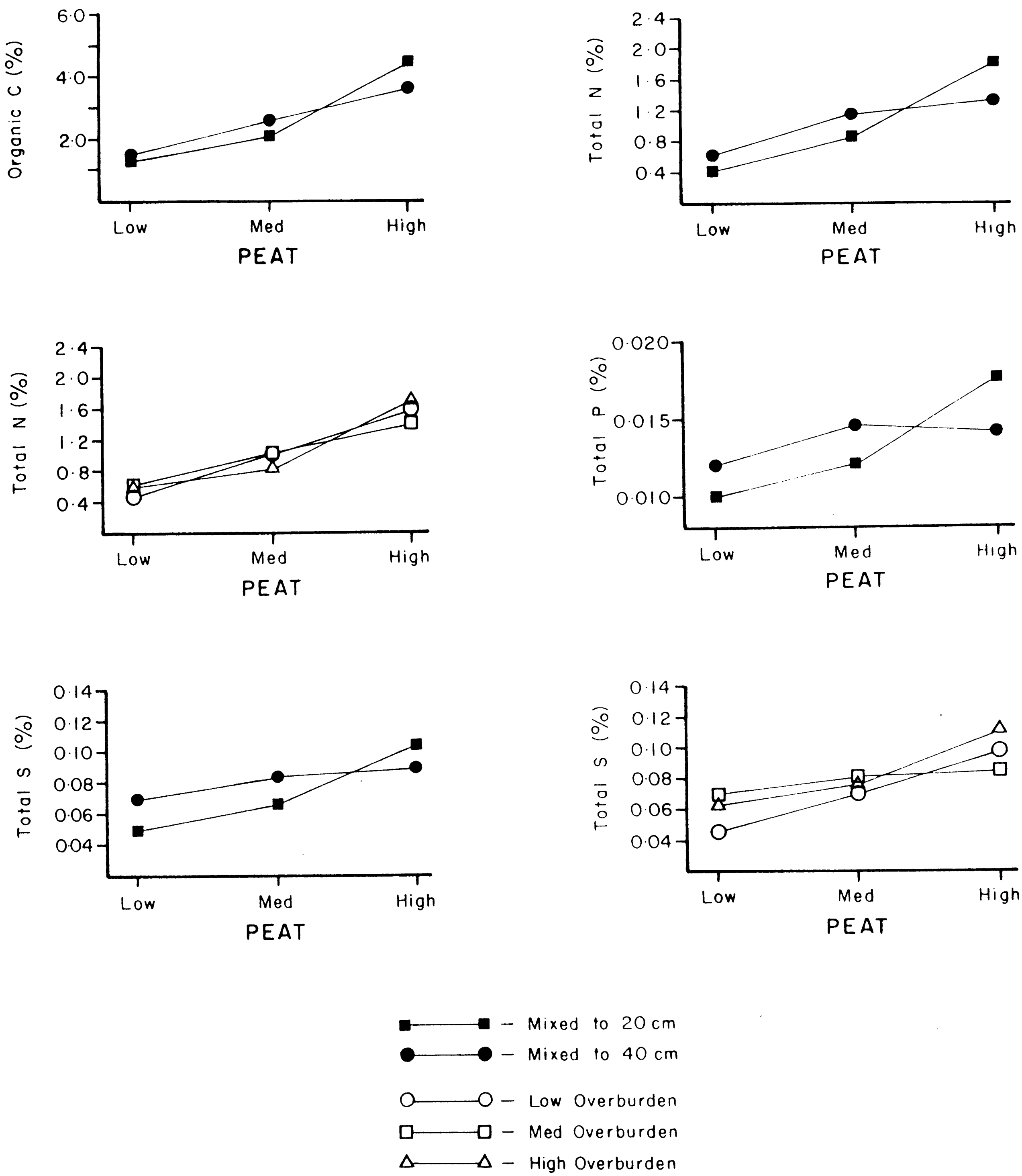

Figure B2. Significant Two-way Interactions for Chemical Properties of the 0 to 20 cm Reconstructed Layer Measured in 1985.

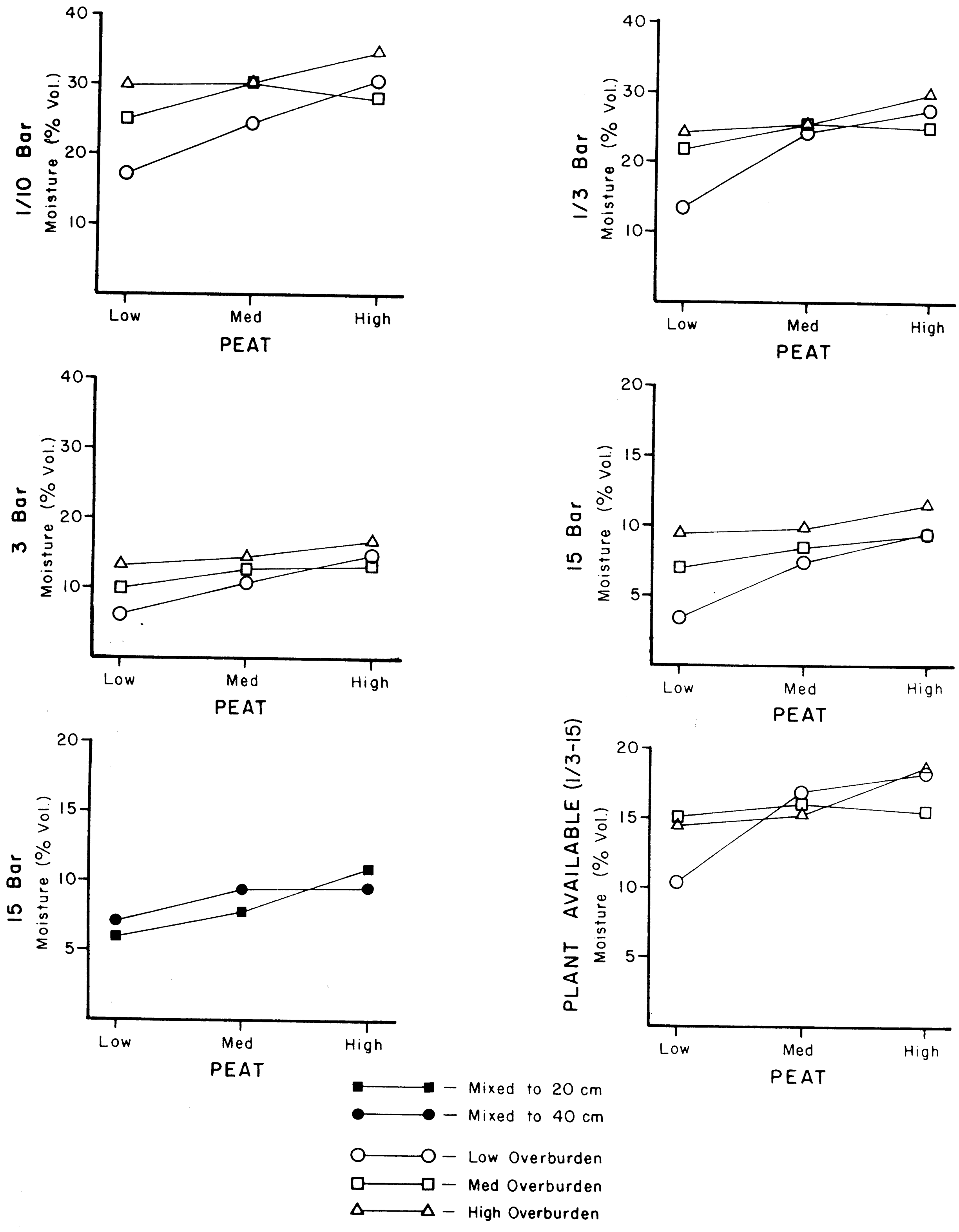

Figure B3. Significant Two-way Interactions for Moisture Retention of the 0 to 20 cm Reconstructed Layer Measured in 1985.

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; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

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 (one at Caw Creek Ridge and two at Cadomin). 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.

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 details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

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. No longer available.**

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. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

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 details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

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 details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

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. $10.00**

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. $10.00**

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. $10.00**

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. $10.00**

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. $10.00**

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 not 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. $5.00**

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. $5.00.**

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.