PROCEEDINGS

OF

THE SECOND ANNUAL GENERAL MEETING

OF THE

CANADIAN LAND RECLAMATION ASSOCIATION

August 17, 18, 19 & 20 — 1977   Edmonton, Alberta

(Sponsored by the Faculty of Extension, University of Alberta)

P R O G R A M

Canadian Land Reclamation Association

Second Annual General Meeting

August 17, 18, 19, 20, 1977

Edmonton, Alberta

Wednesday, August 17 (Optional Field Trips)

Field Trip No. 1 (Athabasca Tar Sands)

Leader: Philip Lulman (Syncrude Canada Ltd.)

Fee: $100.00 (covers bus and air transportation, lunch, and field trip information pamphlets)

Schedule: 7:30 am.- delegates board bus at Parking Lot T, located immediately south of the Lister Hall Student Residence complex. Air transportation from Edmonton Industrial Airport to Fort McMurray and return. Guided bus tour of surface mining and reclamation operations on Syncrude Canada Ltd. and Great Canadian Oil Sands Ltd. leases.
6:30 p.m.- delegates arrive back at Parking Lot T, University of Alberta campus.

Field Trip No. 2 (Aspen Parkland; Forestburg Coal Mine Reclamation)

Leader: George Robbins (Luscar Ltd.)

Fee: $25.00 (covers bus transportation, lunch, and field trip information pamphlets)

Schedule: 8:00 a.m. - delegates board bus at Parking Lot T, located immediately south of the Lister Hall student residence complex. Guided bus tour southeast of Edmonton, stopping at various points of interest (oil spill reclamation field plots; Black Nugget Park [abandoned minesite]; trench plots on Dodds-Roundhill Coal Field; solonetzic soil deep ploughing site) on the way to the Luscar Ltd. Coal Mine at Forestburg.
6:30 p.m. - delegates arrive back at Parking Lot T, University of Alberta campus.

Thursday, August 18

Events:	Opening of Formal Meeting; Presentation of Papers
Location:	Multi-Media Room, located on second floor of Education Building, University of Alberta.
8:00 a.m.	Authors of papers being presented on August 18 meet with paper presentation chairmen and audio-visual co-ordinator (Douglas Patching)
9:00 a.m.	Meeting Opened by Dr. Jack Winch (President of the C.L.R.A.; Head of the Department of Crop Science, University of Guelph). Comments by Dr. Winch.
9:15 a.m.	Welcome to delegates on behalf of the Government of Alberta by the Hon. Mr. Dallas Schmidt, (Associate Minister Responsible for Lands, Alberta Department of Energy and Natural Resources)
9:25 a.m.	Commencement of Paper Presentations. Morning session chaired by Mr. Henry Thiessen (Chairman of the Land Surface Conservation and Reclamation Council and Assistant Deputy Minister, Alberta Department of Environment).
9:30 a.m.	Paper 1. Combined Overburden Revegetation and Wastewater Disposal in the Southern Alberta Foothills by H.F. Thimm, G.J. Clark and G. Baker (presented by Harald Thimm of Chemex Reclamation and Sump Disposal Services Ltd., Calgary, Alberta).
10:00 a.m.	Paper 2. Brine Spillage in the Oil Industry; The Natural Recovery of an Area Affected by a Salt Water Spill near Swan Hills, Alberta by M.J. Rowell and J.M. Crepin (presented by Michael Rowell of Norwest Soils Research Ltd., Edmonton, Alberta)
10:30 a.m.	Coffee Recess
11:00 a.m.	Paper 3. The Interaction of Groundwater and Surface Materials in Mine Reclamation by Philip L. Hall of Groundwater Consultants Group Ltd., Edmonton, Alberta.
11:30 a.m.	Paper 4. Subsurface Water Chemistry in Mined Land Reclamation; Key to Development of a Productive Post-Mining Landscape by S.R. Moran and J.A. Cherry (presented by Stephen Moran of the Research Council of Alberta, Edmonton, Alberta).
12:00 noon	Lunch Recess

1:25 p.m.	Continuation of Paper Presentations. Afternoon session chaired by Mr. Philip Lulman (member of C.L.R.A. executive; reclamation research ecologist with Syncrude Canada Ltd.).
1:30 p.m.	Paper 5. Coal Mine Spoils and Their Revegetation Patterns in Central Alberta by A.E.A. Schumacher, R. Hermesh and A.L. Bedwany (presented by Alex Schumacher of Montreal Engineering Company Ltd., Calgary, Alberta).
2:00 p.m.	Paper 6. Surface Reclamation Situations and Practices on Coal Exploration and Surface Mine Sites at Sparwood, B.C. by R.J. Berdusco and A.W. Milligan (presented by Roger Berdusco of Kaiser Resources Ltd., Sparwood, B.C.).
2:30 p.m.	Paper 7. Agronomic Properties and Reclamation Possibilities for Surface Materials on Syncrude Lease #17 by H.M. Etter and G.L. Lesko (presented by Harold Etter of Thurber Consultants Ltd., Victoria, B.C.).
3:00 p.m.	Paper 8. The Use of Peat, Fertilizers and Mine Overburden to Stabilize Steep Tailings Sand Slopes by Michael J. Rowell of Norwest Soils Research Ltd., Edmonton, Alberta.
3:30 p.m.	Coffee Recess
4:00 p.m.	Paper 9. Oil Sands Tailings; Integrated Planning to Provide Long-Term Stabilization by David W. Devenny of E.B.A. Engineering Consultants Ltd., Edmonton, Alberta.
4:30 p.m.	Paper 10. Bioengineering. The Use of Plant Biomass to Stabilize and Reclaim Highly Disturbed Sites by H. Schiechtel and K. (Nick) Horstmann (presented by Margit Kuttler).
5:00 p.m.	End of August 18 Sessions.

Friday, August 19

Events:	Presentation of Papers; C.L.R.A. Annual General Business Meeting; C.L.R.A. Annual Dinner.
Locations:	Paper presentations and C.L.R.A. Annual General Business Meeting in Multi-Media Room, located on second floor of Education Building, University of Alberta. - Annual Dinner held in Banquet Room located on second floor of Lister Hall.
8:00 a.m.	Authors of Papers being presented on August 19 meet with paper presentation chairmen and audio-visual co-ordinator (Douglas Patching).
8:30 a.m.	Showing of Film Rye on the Rocks. This film depicts reclamation situations at Copper Cliff, Ontario and is being shown for the purpose of introducing delegates to the site of the 1978 C.L.R.A. meeting (Sudbury, Ontario).
8:55 a.m.	Continuation of Paper Presentations. Morning session chaired by Dr. J.V. Thirgood (Vice-President of C.L.R.A.; member of Forestry Faculty, University of British Columbia).
9:00 a.m.	Paper 11. Reclamation of Coal Refuse Material on an Abandoned Mine Site at Staunton, Illinois by M.L. Wilkey and S.D. Zellmer (presented by Michael Wilkey of the Argonne National Laboratory, Argonne, Illinois).
9:30 a.m.	Paper 12. A Case Study of Materials and Techniques Used in the Rehabilitation of a Pit and a Quarry in Southern Ontario by Sherry E. Yundt of the Ontario Ministry of Natural Resources, Toronto, Ontario).
10:00 a.m.	Coffee Recess.
10:30 a.m.	Paper 13. Amelioration and Revegetation of Smelter-Contaminated Soils in the Coeur D'Alene Mining District of Northern Idaho by D.B. Carter, H. Loewenstein and F.H. Pitkin (presented by Daniel Carter of Technicolor Graphic Services Inc., Sioux Falls, South Dakota).
11:00 a.m.	Paper 14. The Influence of Uranium Mine Tailings on Tree Growth at Elliot Lake, Ontario by David R. Murray of the Elliot Lake Laboratory, Elliot Lake, Ontario.

11:30 a.m. Paper 15. Weathering Coal Mine Waste. Assessing Potential Side Effects at Luscar, Alberta by D.W. Devenny and D.E. Ryder (presented by David Devenny of E.B.A. Engineering Consultants Ltd., Edmonton, Alberta).

12:00 noon Lunch Recess.

1:25 p.m. Continuation of Paper Presentations. Afternoon session chaired by Dr. John Railton, (Manager, Environmental Planning, Calgary Power Ltd., Calgary, Alberta).

1:30 p.m. Paper 16. The Distribution of Nutrients and Organic Matter in Native Mountain Grasslands and Reclaimed Coalmined Areas in Southeastern B.C. by Paul F. Ziemkiewicz of the Faculty of Forestry, University of B.C., Vancouver, British Columbia.

2:00 p.m. Paper 17. Systems Inventory of Surficial Disturbance, Peace River Coal Block, B.C. by D.M. (Murray) Galbraith of the British Columbia Ministry of Mines and Petroleum Resources, Victoria, British Columbia.

2:30 p.m. Paper 18. The Selection and Utilization of Native Grasses for Reclamation in the Rocky Mountains of Alberta by D. Walker, R.S. Sadasivaiah and J. Weijer (presented by David Walker of the Department of Genetics, University of Alberta, Edmonton, Alberta).

3:00 p.m. Coffee Recess; Distribution of Proceedings.

3:30 p.m. Commencement of 1977 General Business Meeting of the Canadian Land Reclamation Association. Meeting chaired by Dr. J.V. Winch, C.L.R.A. President.

7:30 p.m. Commencement of C.L.R.A. Annual Dinner in Banquet Room, second floor of Lister Hall.

Guest Speaker: William T. Plass, Principal Plant Ecologist, U.S.D.A. Forest Service, Northeastern Forest Experiment Station, Princeton, West Virginia.

Topic of Speech: Challenges in Co-operative Reclamation Research.

Note: Following the Annual Dinner and Mr. Plass's speech, delegates may retire to the adjacent Gold Room. A bartender will be on service until midnight.

Paper No. 1

Author(s): H.F. Thimm, G.J. Clark and G. Baker

Title of Paper: "Combined Overburden Revegetation and Wastewater Disposal in the Southern Alberta Foothills"

ABSTRACT

A method for rapid reclamation of overburden resulting from the construction of a wastewater lagoon will be presented.

A clay/gravel overburden material, where groundwater movement had been adversely affected by associated construction activities, was revegetated, permitting the harvest of a hay crop three times the local average. This process was aided by irrigation with a moderately saline plant wastewater, thereby solving a water disposal problem as well.

Although the wastewater permitted rapid revegetation, it induced certain changes in the soil chemistry. These changes in soil characteristics, methods of overcoming these, and resulting groundwater changes will be discussed.

COMBINED OVERBURDEN REVEGETATION AND WASTEWATER DISPOSAL IN THE SOUTHERN ALBERTA FOOTHILLS

by

HARALD F. THIMM, G.J. CLARK, AND G. BAKER

CHEMEX RECLAMATION & SUMP DISPOSAL LTD.
CALGARY, ALBERTA

INTRODUCTION

The revegetation of overburden soils resulting from a variety of excavation activities in Alberta is a subject of on-going interest to the resource industries. The coal and oil industries especially have funded or initiated a variety of reclamation studies related to this problem.

The soils under consideration in such studies may fail to revegetate by natural invasion of plant species for a variety of reasons, such as salinity or trace element deficiencies and toxicities, a lack of nutrients and an absence of organic matter, with the latter two contributing in almost every case.

This paper summarizes the results of the first three years of a study conducted at Imperial Oil's Quirk Creek Gas Plant, 10 miles west of Millarville, Alberta.

BACKGROUND

The construction of a wastewater evaporation lagoon at the Quirk Creek Gas Plant a number of years ago resulted in the creation of a six acre area of overburden consisting of heavy clay, gravel and rocks. Until the beginning of a pilot reclamation study in 1974 and 1975, virtually no vegetation had invaded this area. Elevation of the site ranges from 4440 to 4490 feet above sea level, with a mean annual precipitation of 26.28 inches. Land in the surrounding area is used predominantly for cattle grazing.

The water lagoon, covering some 5 acres to a depth of 20 feet is fed by plant discharge resulting mainly from boiler blowdown.

INITIAL DATA

The results of the chemical analysis of composite overburden samples collected prior to revegetation are shown in Table 1. It is evident from these that a salinity or alkalinity restriction to the growth of forage did not exist. N and P nutrients were absent, and even K_2O was low in comparison with most Alberta soils. Organic material was virtually absent also.

Lagoon water quality had been monitored periodically prior to the initiation of overburden reclamation. The data in Table II, although gathered in 1976, serves well to illustrate the range of ion concentrations found.

It will be recognized that, with the exception of sodium and bicarbonate ions, all species present are essential for plant growth, and in principle the water could be used as a continous low-level source of nutrients during the revegetation period. If establishment and maintenance of a grass-legume cover were possible by this method, soil organic matter would be rapidly restored.

Amounts of water application could not be governed by nutrient requirements of vegetation alone, however. The United States Salinity Laboratory classifies waters of the quality in Table II as possessing a low sodium - high salinity hazard for irrigation pruposes (1), although this classification is based on data gathered in regions more arid than the southern Alberta Foothills. Consideration of these factors and the required moisture balance suggested the following procedure.

TABLE I

COMPOSITE SOIL ANALYSIS PRIOR TO REVEGETATION (SATURATED EXTRACT)

pH		7.9
Conductivity	umho/cm	170
Na^+	ppm	5
Ca^{++}	ppm	155
Mg^{++}	ppm	27
Cl^-	ppm	<5
$SO_4^=$	ppm	<5
HCO_3^-	ppm	37
S.A.R.		0.1
NO_3-N	lb/acre 6"	0
P_2O_5	lb/acre 6"	0
K_2O	lb/acre 6"	38

TABLE II

1976 LAGOON WATER QUALITY

		May	July	August	September	October	Comments
pH		7.6	7.8	7.4	7.7	7.0	a) Nitrate-N
E.C.	umho/cm	1390	1550	1410	1500	1730	b) Total N
Na^+	ppm	230	120	180	190	200	
Ca^{++}	ppm	65	65	65	71	82	
Mg^{++}	ppm	25	40	33	32.4	40	
K^+	ppm	3	5	3.6	4.9	4.5	
HCO_3^-	ppm	322	346	312	342	361	
$SO_4^=$	ppm	265	60	428	210	349	
Cl^-	ppm	177	187	156	139	208	
NO_3^-	ppm	0.04[a]	0.04[a]	0.03[a]	9.5[b]	0.055	
PO_4	ppm	0.812	0.3	0.125	0.14	0.21	
NH_3	ppm	1.4	---	---	---	---	
Fe	ppm	2	3	4	---	---	

There appears to be a relationship between changes in lagoon water quality and the concentrations of sulphate and choride ions in the groundwater, as might be expected for ions with high mobility within soil profiles. However, a statistical evaluation of this relation must await further data.

Changes in soil analyses were in part unexpected. In contrast with the above mentioned U.S.D.A. water classification, it was found that salts did not accumulate in the root zone to any large extent, presumably owing to the large volumes of water the site receives annually.

Instead, sodium was found to accumulate. By the end of 1975, the sodium absorption ratio (S.A.R.) of a saturated soil extract had increased from the original value of 0.1 to a value of 3.0. Since it was not known to which extent this rise in the S.A.R. might continue, the S.A.R. has since then been stabilize with minor additions (approximately 500 lbs/acre) of gypsum or calcium nitrate to the soil each spring. Changes in the S.A.R. and specific conductance of the soil are shown graphically with time in Figure II.

Present soil organic matter is in excess of 10% of soil weight, and the black soil layer extends to a depth of eight inches

EXPANSION OF THE IRRIGATION SYSTEM

Following the initial favourable results of 1975, the irrigated area was expanded to include some 2 1/2 acres to the sout of the lagoon, where soil had been disturbed by construction of a pipeline in the spring of 1976 (Figure I).

The approach to revegetation of this area was essentially similar to that described above, except that ploughing was not necessary and that sweet clover and brome only were seeded.

THE REVEGETATION PROGRAM

In 1975 the site in question was ploughed thoroughly, and N and P nutrients added at the rate of 54 lbs. of nitrogen and 28 lbs. of P_2O_5 per acre. Following this, the site was seeded to a grass-legume mixture containing 45% brome, 45% timothy, 5% sweet clover and 5% alfalfa.

This mixture was chosen for the relative salt or moisture tolerance of its constitutents.

Lagoon water was then applied by means of a sprinkler system at the rate of two inches per week during a 100-120 day irrigation season.

A groundwater observation well was drilled for monitoring of groundwater, which, together with the lagoon water and soils, was periodically sampled and analyzed. The design of the irrigation system is shown in Figure I.

RESULTS

In the first season, during which 6 acres were irrigated, excellent germination of grasses and legumes was found, and in the fall of that season the field was cropped for hay with a yield of 2 1/2 tons per acre, as opposed to 1 ton per acre for pastures in the vicinity. While cropping was neglected in 1976, a yield of some 3 1/2 tons per acre is anticipated for 1977. Groundwater quality was unknown prior to irrigation, but has shown little change over three years under a variety of conditions including lengthy periods of rainfall when irrigation temporarily ceased. The 1976 groundwater data are shown in Table III, and are comparable to those from other groundwater wells in the southern Alberta Foothills.

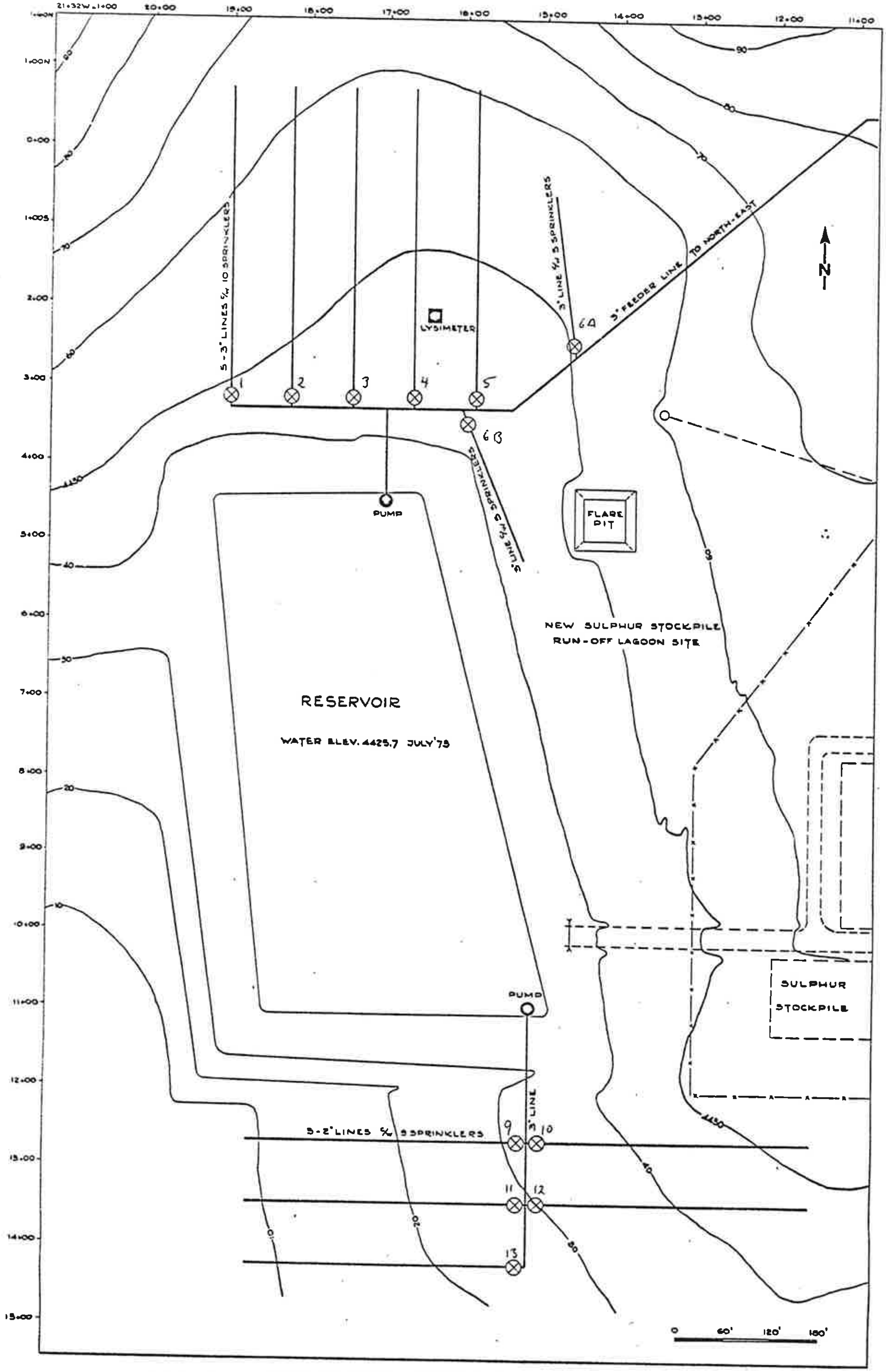


FIGURE 1 NORTH AND SOUTH PLOTS

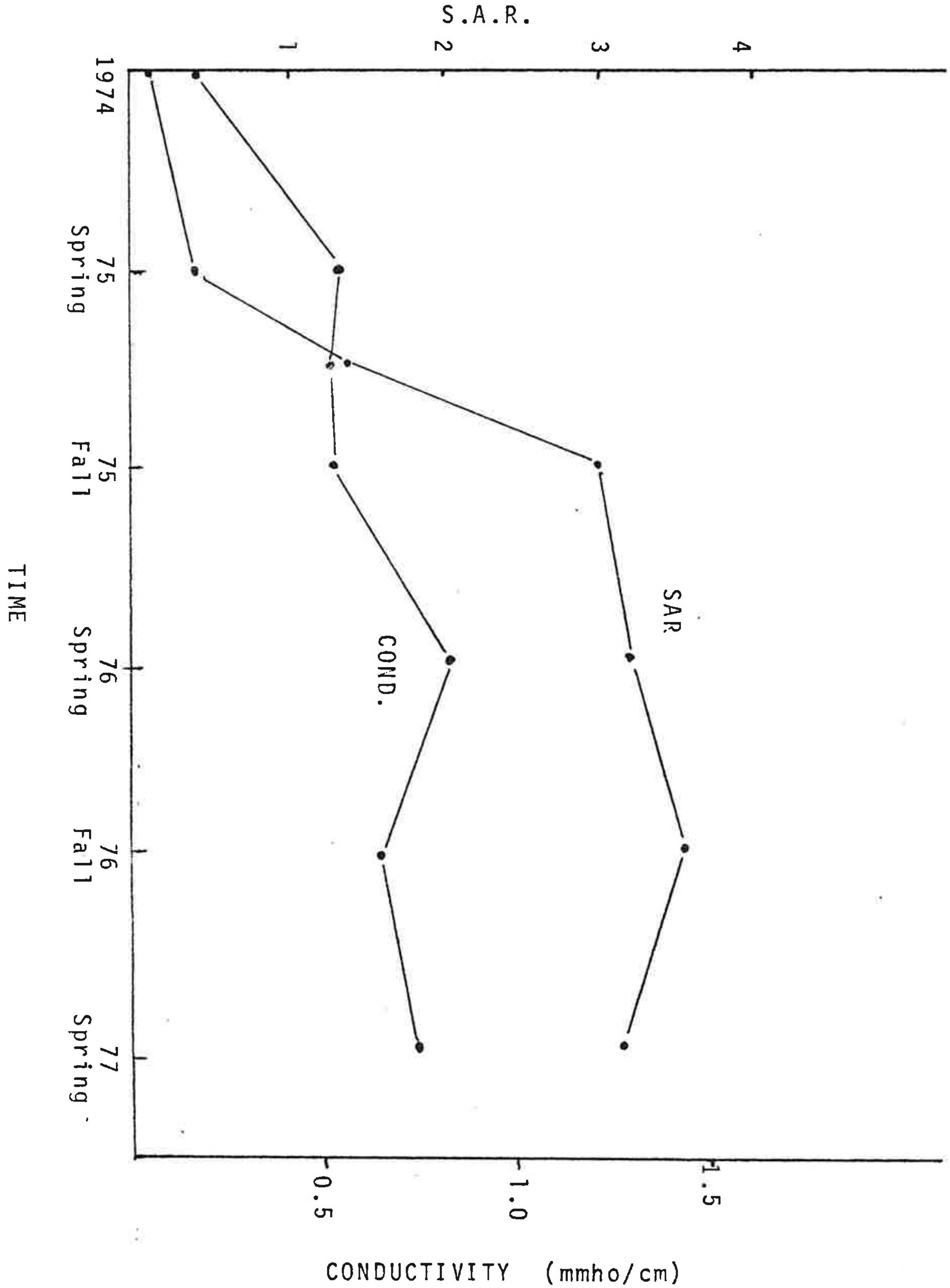
TABLE III

1976 GROUNDWATER QUALITY

		May	July	August	September	October	Fall 1975
pH		7.2	7.9	7.4	7.5	7.6	7.1
E.C.	umho/cm	1450	1550	1440	1500	1500	1300
Na^+	ppm	130	240	105	110	95	160
Ca^{++}	ppm	125	80	130	125	120	69
Mg^{++}	ppm	80	90	78	78	80	75
K^+	ppm	3	3	3	3.4	3	1.5
HCO_3^-	ppm	493	738	566	549	537	566
SO_4	ppm	188	143	338	100	248	160
Cl^-	ppm	128	128	124	99	119	125
NO_3^-	ppm	0.04[a]	0.08[a]	0.06[a]	4.2[b]	0.03[a]	<0.1
$PO_4^{\equiv}$	ppm	0.01	0.39	0.12	0.35	0.32	0.075
NH_3	ppm	1.3	---	---	---	---	0.32
Fe	ppm	---	6.0	5.4	---	---	<1

a) Nitrate - N

b) Total N


S.A.R.
1
2
3
4
1974
75 Spring
75 Fall
76 Spring
76 Fall
77 Spring
TIME
SAR
COND.
0.5
1.0
1.5
CONDUCTIVITY (mmho/cm)

An additional two acre area to the northeast of the lagoon was included also. This area, covered by a variety of deciduous trees and brush, had not been disturbed, and its inclusion merely reflects a change of emphasis from revegetation to an economically attractive method of wastewater disposal. Although only limited data are available for these two areas at present, it appears that soil changes in the south plot are essentially similar to those already described, while in the sandier soil of the northeast plot no chemical changes have as yet been discernible.

SPECIES PERFORMANCE

The progression of grass species in the north and south plots is of some interest.

In the north plot, the density of the vegetation has increased each year since 1975. Although a condensate spill occurred on a major portion of this site in the spring of 1977, after burning and the usual calcium addition (calcium nitrate was used), no detrimental effects were observable one month later.

The species abundance has changed greatly since 1975. In July 1977, an approximate abundance estimate of 80% timothy, 5% sweet clover and 5% brome was made. The remaining 10% is made up of intermediate wheatgrass and Canada bluegrass which have invaded the site. Alfalfa is completely absent.

In part of the south plot, the soil material was superior, in terms of organic matter content, to that originally present in the north plot. However, only patchy emergence of smooth brome and sweet clover were found after the 1976 seeding, with a large variety of annual weeds covering most of the site. This area, with the exception of a narrow band immediately above the pipeline, was not reseeded in 1977. The result has been that the clover and brome seeded in the spring of 1976 did not germinate until the spring of 1977. A crop of 1 1/2 tons per acre of hay is expected this year.

Monitoring of relative species abundance is continuing.

A recent report by Steward and Macyk (2) from work in the Grande Cache area mentions alfalfa, brome and timothy as successful species for overburden revegetation in the Alberta foothills, although no indication of changes in species abundance is given.

Under our conditions, which differ significantly from those of the Steward and Macyk study, at least the initial success with brome and timothy was high, even though timothy was eventually found to be superior. Sweet clover, however, was found to be a much superior legume to alfalfa.

ACKNOWLEDGEMENTS

The authors are indebted to Imperial Oil Limited for funding this study and for granting permission to publish.

LITERATURE CITED

1. "Saline and Alkali Soils", Agriculture Handbook 60, U.S.D.A., L.A. Richards (Ed.) 1969.

2. J. Steward and T.M. Macyk, Coal Industry Reclamation Symposium, Banff, 1977.

PAPER

-2-

BRINE SPILLAGE IN THE OIL INDUSTRY - THE NATURAL RECOVERY OF AN AREA AFFECTED BY A SALT WATER SPILL NEAR SWAN HILLS, ALBERTA

By Micheal J. Rowell and Jean M. Crepin*

Norwest Soil Research Ltd.

Abstract

Salt spills are liable to become more prevalent in the oil producing regions of Alberta as the volume of brine relative to crude oil increases with the depletion of the older oil-fields.

High concentrations of sodium chloride can cause severe damage to vegetation and produce long lasting structural damage to soils. Although current knowledge into the reclamation specifically of areas affected by oil-field salt water is not well advanced, certain treatments are commonly employed. These involve calcium saturation of the soil, leaching with freshwater, addition of manure and fertilizer and reseeding with salt tolerant plant species.

The results presented in this paper suggest that with certain organic soils, extensive treatment of spill areas may not be needed. A three year monitoring program of an area near Swan Hills, Alberta showed a gradual reduction of salts within the original spill area and a migration of salts into the surrounding drainage areas. The spill had occurred in a very wet area of treed Black Spruce/Sphagnum bog which was readily leached at the surface. In 1975, soil and water samples contained up to 22,400 ppm of chloride and 34,500 ppm of sodium. By 1977 the maximum contents of chloride and sodium recorded at the site were 4467 ppm and 2781 ppm respectively.

Extensive damage to the trees and ground vegetation was observed in 1975. Regrowth was active throughout the area in 1977 except in one small part near the original pipeline leak.

The main drainage catchment area is a small lake to the northwest of the spill. Concentrations of chloride in the lake have increased from 180 ppm in 1975 to 372 ppm in 1977.

If more conventional techniques used in the reclamation of saline soils had been employed additional damage to the area may have been produced. The extreme acidity of the soil and the saturated condition of the site would have made the establishment of non-native plant species almost impossible.

Although the treatment of most mineral soils that have been affected with brines would require a considerable reclamation effort, many organic soils may best be left to reclaim naturally.

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1. INTRODUCTION

Considerable quantities of salt water may be recovered when crude oil is pumped from producing wells. The ratio of salt water to crude oil varies widely depending upon the nature of the oil-bearing formations and the degree to which the oil-field has been exploited. Data from the early 1960s shows that the ratio of salt water to crude oil was as high as 17:1 in producing areas in Kansas and approximately 2.5:1 in Texas [(1)]. In Alberta, the production of salt water relative to crude oil has been rising steadily with time as some of the older fields are becoming depleted and salt water moves into the formations. Table 1 shows some data for between 1951 and 1974 to illustrate this trend.

Table 1. Volumes of salt water and crude oil produced annually in Alberta (1951-1974).

Year	Salt water (bbl/yr x 10^6)	Crude oil (bbl/yr x 10^6)	Ratio salt:oil
1951	1.5	43.9	0.034
1956	11.2	143.9	0.078
1969	54		
1974	188	500	0.376

Data compiled from references 2,3, and 4.

The recovered salt water and oil are transported to tanks where the oil is allowed to separate from the salt water and other residues. In the early days of the petroleum industry in the United States these brines were discharged into rivers, lakes and freshwater aquifers or even directly onto land. The damage to water supplies and farming land lead to legislation that required a safer form of disposal. Around this time much of the salt water was stored in pits where the salts could be concentrated by evaporation. Many of the pits were unlined which often resulted in subsurface percollation and seepage problems. Some improvement occurred where disposal pits were lined with materials such as concrete, gunite, asphalt, vinyl or other plastics. At present the great majority of oil-field brines are returned underground into the original producing formations through injection wells or deep disposal wells.

In Alberta, since spill reporting to the Energy Resources Conservation Board was made mandatory in 1971, data shows that the amount of salt water spilled annually has been on the increase. In 1971 a total of 4,835 barrels was spilled while by 1974 the volume had risen to 70,755 barrels [4]. This may be compared to spills of crude oil which between 1971 and 1975 amounted to an average of about 69,000 barrels per anum. Although a few salt water spills exceed 1,000 barrels in size, most are below 500 barrels in volume. The majority occur on land and are the result of pipeline failures or accidents at storage facilities. Spillages that occur between the producing well and the battery site can involve a mixture of crude oil and salt water.

The chemical composition of oil-field brines varies depending upon location. Several references give examples of the analysis of a great variety of brines both from the United States and Canada [2,3, 5-10]. Although the total salt content may be high as 650,000 ppm., the average is found to be about 40,000 to 45,000 ppm. This is more saline than seawater (normally 20,000 to 35,000 ppm) and far in excess of the concentration of salts in freshwaters (normally less tha 100 ppm). Most of the salt in oil-field brines is made up of sodium chloride although, significant amounts of calcium, magnesium and potassium may occur in association with chloride, sulfate, carbonate and bicarbonate anions. In addition the following may be found at a concentration of below 100 ppm ; Si, NH_3, Fe, Al, Br, Li, Rb, Sr, B and Ba. Other elements such as Cr, Cu, Mn, Ni, Sn, Ti, Zr, Be, Co, Ga, Ge, Pb, V, W and Zn have also been detected in the ppb. range. Table 2 shows an analysis of the major components in two Swan Hills brines from Alberta [(9)] which are probably similar in composition to the salt water involved in the spill that will be described later.

Salt spillages may cause severe damage to vegetation and have long lasting effects on the chemical and physical properties of soils. There are numerous reports in the literature dealing with the impact of salts from a variety of sources on plant growth. Several good reviews and books are available for those requiring a detailed treatment of the subject (e.g. references 11-13). The more direct effects of high salt concentrations on plants come under the general heading of plasmolysis. Loss of cell semipermiability results from damage to the membrane lipids and protein denaturation and aggregation. The deactivation and denaturation of enzymes leads to a complete breakdown in the biochemical functioning of the cell. Secondary affects may be related to the creation of conditions of physiological drought and ionic imbalance. A high salt concentration in the soil solution means that plants must exert more effort to obtain water. The predominance of sodium and chloride will upset the normal uptake of other essential cations and anions.

The tolerance of different plants towards salt varies between the species

Table 2. Analysis of salt water from two sources from Swan Hills, Alberta*

Source	pH	Cond. (mmhos/cm)	Total salts (ppm)	Ca	Mg	Na	K	Cl'	SO_4''	HCO_3'	CO_3''
				ppm							
AMOCO Battery No. 1.	6.8	72.7	72630	1710	212	22400	318	34612	324	276	0
AMOCO Battery NO. 8.	6.7	56.6	45940	1485	160	16000	250	24424	498	286	0

* Data adapted from Edwards and Blauel, reference 9.

involved and the stage of plant development. Many publications give listings of the relative tolerances of different species (e.g. references 11, 14 and 15). Table 3 shows the relative susceptabilities of some plants of economic importance in the Prairie regions of Canada. It is difficult to place precise limits

Table 3. Relative tolerances of different agriculturally important plants towards salts.

Very high tolerance	High tolerance	Moderate tolerance	Low Tolerance
Nuttall alkali grass	Tall wheatgrass	Smooth brome grass	Red clover
Salt grass	Slender wheatgrass	Crested wheatgrass	Alsike clover
Alkali Grass	Russian wild rye	Intermediate wheatgrass	Red top
Birdsfoot trefoil		Reed canary grass	White Dutch cl
Western wheatgrass		Meadow fescue	Timothy
Canada wild rye		Cicer milk vetch	Soybeans
		Flax	Field beans
		Oats	Peas
		Barley	Sunflower
		Rye	
		Wheat	
		Rapeseed	
		Corn	
		Sugar beets	
		Alfalfa	

upon salt effects in soil from the results of soil analysis. Table 4 shows, by way as a rough guide, the commonly accepted limits for salt damage to plants.

Table 4. The relationship between soil electrical conductivity and plant growth

Conductivity * (mmhos/cm @ 25° C)	Effect
0-2	Salinity effects mostly negligible
2-4	Growth of very salt sensitive plants may be restricted
4-8	Growth of many plants is restricted
8-16	Only salt tolerant plants grow well. Other plants may fail to germinate or show greatly reduced growth.
16+	Only a very few salt tolerant plants grow well. Few seeds germinate.

* measured in a saturated soil extract

The ability to withstand the effect of saline spills may involve avoidance or tolerance mechanisms. Avoidance of high salt concentrations is involved in the exclusion, excretion or dilution of ions. Tolerance is concerned in the accumulation of salts in vacuoles, the ability to replace K by Na within the cell and a genetically based resilience to withstand ionic imbalances, cellular dehydration and nutrient deficiencies. For example, the death of Black Spruce was thought to occur when about 7,000 ppm of chloride were accumulated in the needles while death did not occur with Birch until the leaf concentration was 30,000 ppm (9). However, chloride was taken up more readily by Birch, which was considered to be a tolerant species while Black Spruce seemed to rely more on avoidance mechanisms.

Outward symptoms of salt damage vary from mild chlorosis of the tissues to browning and blackening and eventual death. Certain plants exhibit very distinctive colorations such as the magenta color found on salt damaged Spruce needles.

Many discussions of soil salinity problems can be found in the literature. The majority are concerned with various aspects of naturally saline soils where the problems have been created by the presence of soluble salts such as sodium sulfate, carbonate and bicarbonate which have been derived from saline parent materials. Reports of the addition of salty materials to soils are limited to the reclamation of coastal soils (especially in the Netherlands), the environmental effects of salting roads with NaCl and $CaCl_2$, the addition of heavy applications of fertilizer tc soils and a small number related to oil-field brines. Much of this research covers fairly common ground since it is primarily the sodium ion which is responsible for the deterioration in the properties of the soil.

In well drained mineral soils the colloidal particles are aggregated together and help to maintain a good pore structure. If high concentrations of sodium are added to the soil many of the cations held on the exchange sites on clays and organic matter are replaced. Sodium is ineffective in holding colloidal particles together so that when the ionic concentration of the soil solution is reduced by the residual salt leaching away, the colloidal particles become dispersed. The soil pores become blocked by clay particles and aeration and water movement are greatly reduced. The process is not irreversible and some improvement may occur if the soil can be saturated with calcium ions.

In organic soils the long term effects of salt are generally not as severe as with mineral soils. Most damage occurs due tc the death of surface vegetation and plant roots in response to the high osmotic potential. Edwards and Blauel [9] suggest immediate flushing of such soils with freshwater or water saturated with gypsum or lime.

As with the effect of salt on plants, it is difficult to set definite limits on likely salt damage to soils. In terms of analytical parameters salt damage can probably be expected when the S.A.R. value* exceeds about 10 to 15 and when the exchangeable sodium percentage or E.S.P. exceeds about 5% (i.e. Na exceeds 5% of the total exchangeable cations).

Discussions on the possible reclamation of soils damaged by oil-field brines rely heavily upon information obtained from similar research on naturally saline or alkaline soils (e.g. references 9, 10, 16-19). Comparitively few reports have evaluated the usefulness of different methods in the field. Clark and Thimm [16] have studied two spill sites on mineral soils. Different reclamation methods involved treatment with gypsum (up to 2.6 tons/ac), the addition of fertilizers and leaching. Particularly good results were obtained when addition of calcium nitrate was combined with heavy irrigation. Plice[19] found that the application of up to 6 tons of sodium chloride per acre created bad soil structure and resulted in leaching of silicates and about 67% of the soil organic matter from the soil surface. The recommended reclamation was the addition of 4-6 tons of gypsum per acre and possibly the application of manure. Clearly much more research is needed in this area if we are to evaluate salt

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* The sodium absorption ratio (S.A.R.) = $Na/\sqrt{\frac{1}{2}(Ca + Mg)}$, where the cations are expressed in millequivalents per litre in the saturation extract.

damaged soils and successfully propose adequate reclamation methods.

The study reported in this paper deals with the unaided recovery of a salt spill in the Swan Hills area of Alberta.

2. METHODOLOGY

The area is located about 4 miles west of the town of Swan Hills at the legal location 7-20-66-10 W5M.

The first signs of damage in the area was the appearance of reddened needles on some Spruce trees nearby the road to the west of the spill site. At first it was thought that the source of the damage might be an old oil spill nearby known as the Pan Am A-3 spill (see in the Figures).

The area was visited first in June of 1975 and samples of soil, water and plant tissues were taken for analysis. From the analysis it was possible to show that a spill of salt water was involved and to indicate the extent of the area affected. At this time it was thought unwise to take any further steps to reclaim the area since the soil was highly acidic and the whole region was very wet and poorly accessible. Consequently the spill was monitored over the next two years to make sure that the environmental condition of the site did not deteriorate further.

Soil, water and plant analyses were carried out by aproved standard methods. Soil pH was determined in a 2.5:1 water/soil paste. Electrical conductivity was determined in a saturated soil extract. Chloride and sodium were measured after the extraction of soil with water at a ratio of between 2.5 and 5 parts water to one of soil. Sodium was determined by atomic absorption spectroscopy and chloride either by titration against silver nitrate or using a specific ion electrode.

3. RESULTS AND DISCUSSION

In 1975 extensive damage to the vegetation had occurred. The area primarily affected by the salt (outlined in the figures) was a very wet region of partially treed bog dominated by Black Spruce and Sphagnum Moss. Many of the trees within the central and eastern parts of the spill had been killed. These were mainly dwarf Black Spruce, Tamarak and Willows. The ground vegetation of Sphagnum, sedges and grasses had also been damaged. Large brown patches of dead plants could be seen over this area. Around the perimeter of the boggy area and more to the west the damage to the vegetation was not as serious. Many of the White and Black Spruce trees had magenta colored needles and were showing signs of die back of the branches.

The location of samples taken in 1975 is shown in Figure 1. The results of analysis are compiled in Table 5. Soil samples were taken to a depth of 54" in places but only the analysis for the 0-6" (0-15 cm) depth is given in the table.

All the soils were very acidic and had pH values ranging from 4.03 to 5.45. The generally acidic nature of the area was also reflected in the pH of the water samples that were taken. Analysis for chloride and sodium indicated firstly that the oil spill was in no way responsible for the damage that was observed. High amounts of soluble salts could be detected throughout the wet boggy area and in places in the surrounding drier treed area. Contamination by sodium and chloride extended from the pipeline to slightly beyond the roadway in the west. The most heavily contaminated area was around the pipeline and immediately west and south. At this time much of this area was very soft and

Table 5 . Analysis of soil and water samples from a salt spill at Swan Hills, Alberta - June, 1975.

Sample	pH	Cond. (mmhos/cm)	Chloride (ppm)	Sodium (ppm)	SO_4-S (ppm)
Water samples:					
1	6.36	5.32	1200	1260	4.0
2	4.73	4.41	1060	1010	0.3
3	4.50	0.55	110	60	0.2
4	5.14	0.53	100	110	0.3
5	5.05	0.58	110	50	0.2
6	5.56	0.52	100	100	0.1
7	6.24	0.21	30	25	0.3
8	5.03	0.91	180	170	0.8
9	5.54	0.52	100	165	0.3
10	5.12	4.86	1050	1020	0.1
Soil samples (0-15 cm):					
A	4.50	0.15	10	100	30
B	4.75	0.09	40	130	40
C	4.53	0.26	10	70	80
D	4.65	5.47	2500	5800	35
E	5.12	5.47	3100	5000	40
F	4.82	10.64	22400	34500	30
G	5.15	1.73	4750	12000	45
H	4.80	0.79	950	3800	80
I	4.38	0.84	900	2100	40
J	5.45	0.79	1950	2600	55
K	4.78	1.06	2100	2400	150
L	4.64	1.00	3950	3200	50
M	4.56	1.40	2200	3000	115
N	4.40	1.25	2850	3150	60
O	4.40	1.08	2250	8600	95
P	4.03	0.67	650	330	15
Q	4.54	1.08	1500	1650	50
R	4.50	0.78	2050	3200	25
S	4.40	0.40	2350	2200	20
T	4.17	0.65	880	860	100
U	4.56	0.85	1600	3150	75
V	5.02	3.19	7000	6300	215
W	4.33	0.50	900	825	125
X	4.52	7.60	21550	24000	60
Y	5.27	0.88	1550	1650	65
Z	5.19	8.51	19050	30000	165

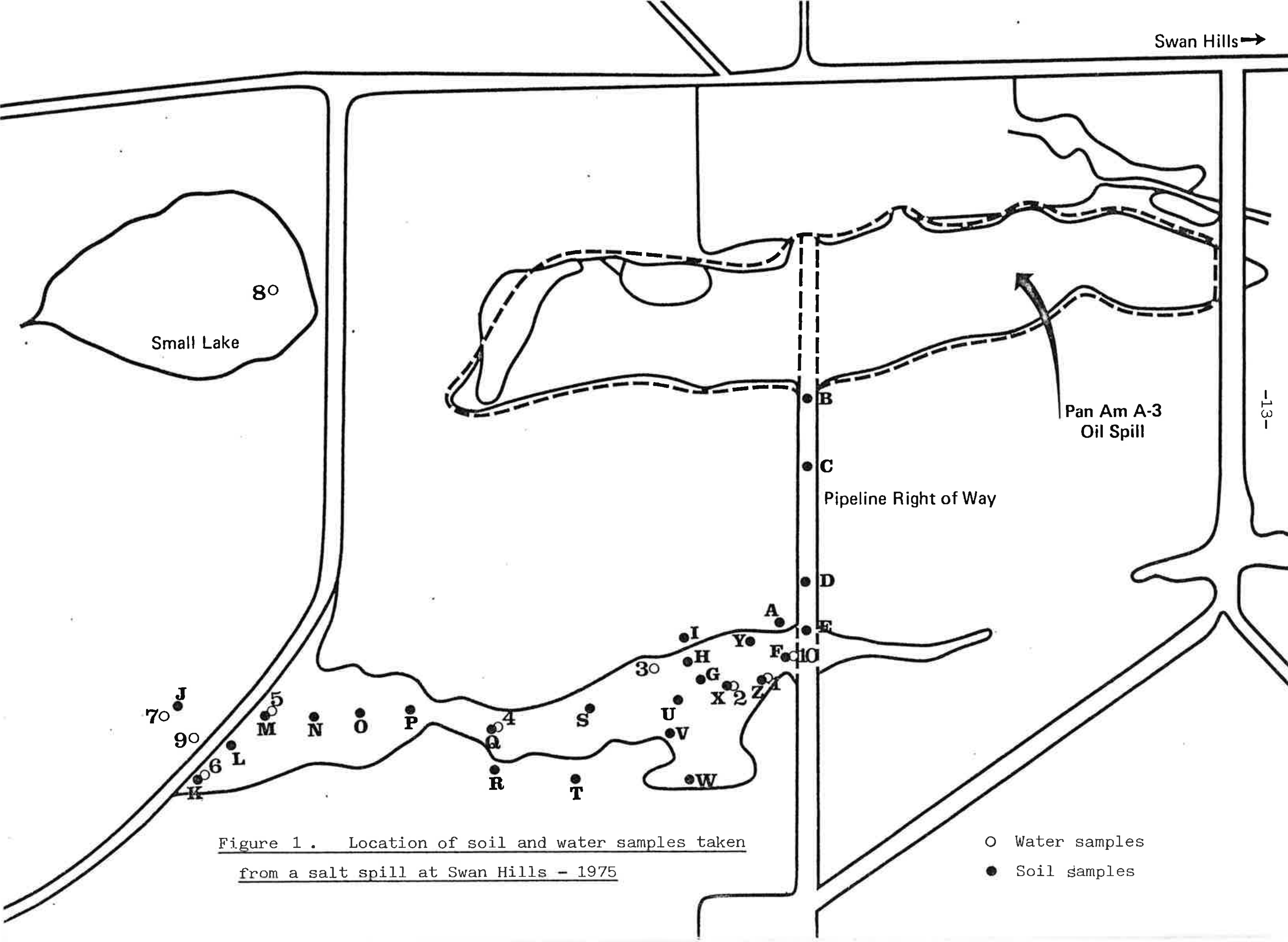

Figure 1. Location of soil and water samples taken from a salt spill at Swan Hills - 1975

and had lost its physical structure due to the destruction of the ground vegetation. The worst areas were so difficult to approach that they could not be sampled. A map of the chloride contents throughout the site can be found in Figure 2. Drainage of the site seemed to occur slowly in an east to west direction. Analysis of the water in the small lake about 3/4 mile away showed that some runoff containing sodium and chloride had already collected there. At this time the concentration of sodium and chloride was 180 ppm and 170 ppm respectively.

The electrical conductivity of soil and water samples that were taken in 1976 was considerably reduced over the previous year (see Table 6). Signs of vegetative regrowth could be seen all over the site. A relatively small area around the pipeline and to the south and west was still almost completely bare of vegetation. In other areas new Black Spruce and Tamarak seedlings had appeared and some new growth had been started on many of the damaged moss hummocks. A few of the dwarf Black Spruce and Tamarak which appeared dead the previous year had produced new shoots on some of the branches. In the far west end of the spill towards the road signs of salt damage were almost absent.

The location of soil and water samples taken in 1976 is shown in Figure 3. It was still not possible to reach the worst affected part on foot. Analysis showed that the concentrations of sodium and chloride had declined since 1975 (see Table 6). The maximum concentrations recorded were 9324 ppm for chloride and 5600 ppm for sodium as compared to 22,400 ppm for chloride and 34,500 ppm for sodium in 1975. Analysis of water from the culverts and ditches along the roadway showed that the salt was migrating generally towards the small lake and to a certain extent southwards. The concentration of chloride in the lake was slightly higher than the previous year although sodium was slightly less. Other water samples taken from around the Pan Am A-3 oil spill did

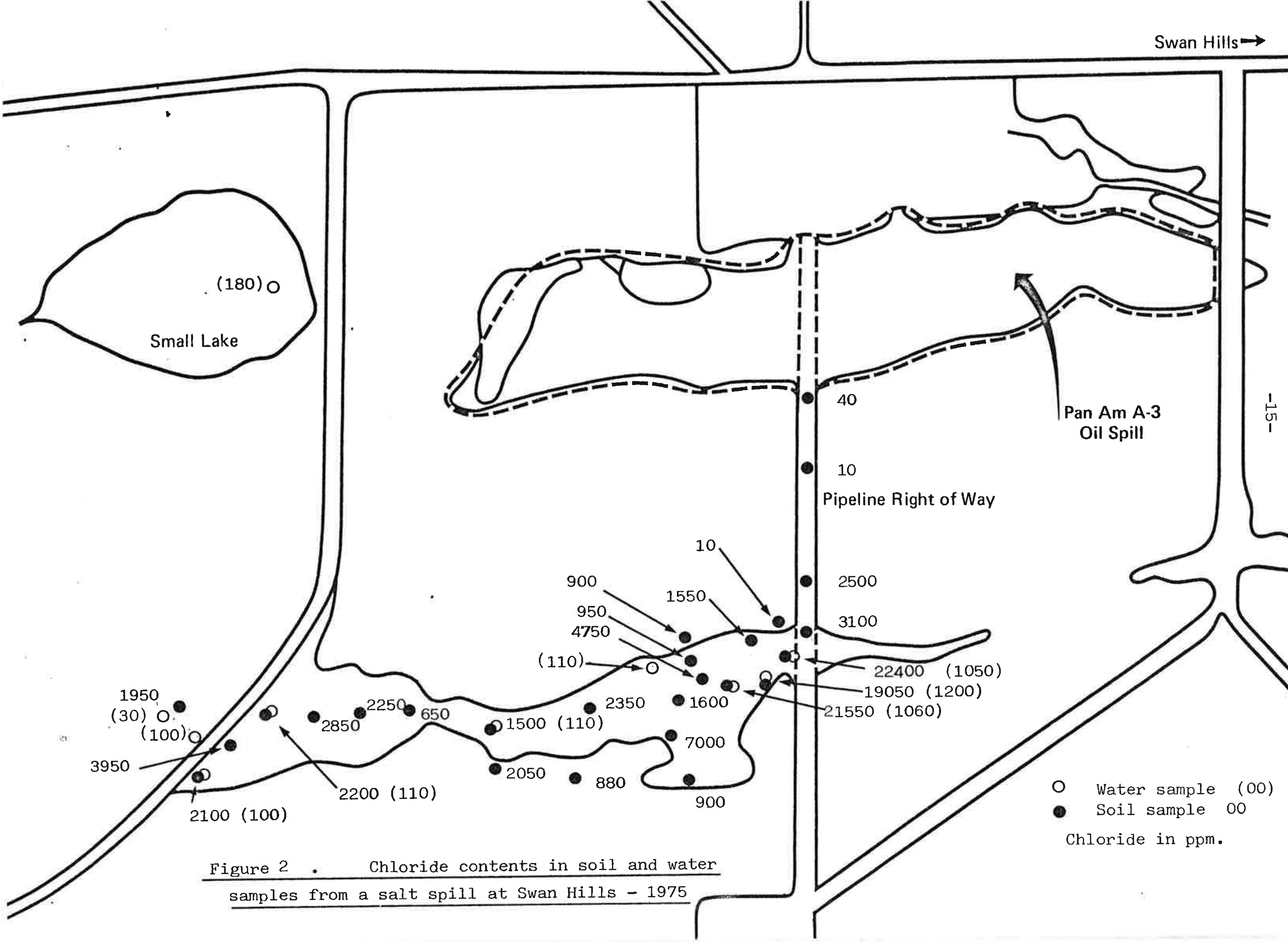

Figure 2 . Chloride contents in soil and water samples from a salt spill at Swan Hills - 1975

Table 6. Analysis of soil and water samples from a salt spill at Swan Hills, Alberta - August, 1976.

Sample	pH	Cond. (mmhos/cm)	Chloride (ppm)	Sodium (ppm)
Water samples:				
1	6.1	0.45	160	84.0
2	6.6	0.31	96.2	50.0
3	6.8	0.42	122	70.0
4	6.8	0.28	86.7	108
5	4.7	1.58	600	336
6	5.4	0.30	98.2	50.0
7	6.3	1.00	338	200
8	4.8	0.80	283	140
9	5.8	0.02	2.0	2.5
10	6.1	0.03	2.0	2.8
11	5.8	0.04	3.2	8.6
12	5.4	0.27	106	70.0
13	4.3	0.39	138	96.0
14	4.8	0.51	194	104
15	4.9	0.59	212	120
16	4.4	0.20	66.4	9.5
Soil samples (0-15 cm):				
A	5.7	0.36	950	1040
B	4.0	2.64	9324	5600
C	4.5	1.82	6672	4400
D	4.0	0.23	594	1200
E	5.1	1.68	6256	5200

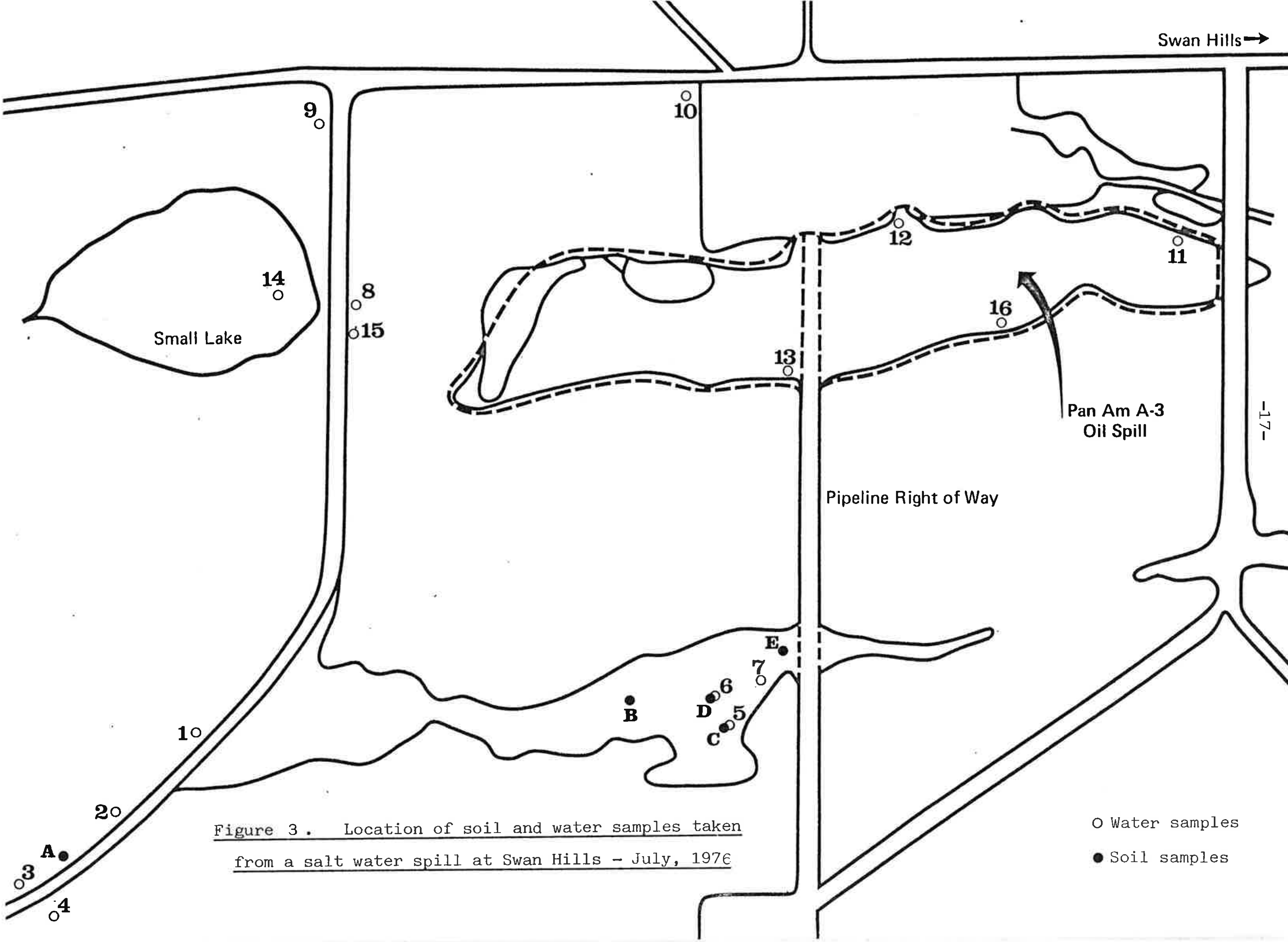

Figure 3. Location of soil and water samples taken from a salt water spill at Swan Hills - July, 1976

contain above normal levels of sodium and chloride but the contamination here was unlikely to be directly related to the main spill. Possibly some brine is leached from the battery site which tends to drain into the oil spill near where sample # 12 was taken from. Figure 4 shows the levels of chloride in the spill area in 1976.

Another visit to the area was made recently in July, 1977. Figure 5 shows the location of soil and water samples that were taken at this time. Improvement in the recovery of the vegetation over the previous two years was quite dramatic. Even the barren areas were showing good signs of growth and had regained enough structure from the new growth that they could be walked on with little danger. The more severely affected parts near the pipeline were being invaded by Slough Grass (*Beckmannia syzigachne*), Common Cattail (*Typha latifolia*), Marsh Ragwort (*Senecio palustris*), Fireweed (*Epilobium angustifolium*) and a variety of sedges and rushes. Moss hummocks that were brown the year before now showed a healthy growth of green tissues this year. Considerably more small trees of Black and White Spruce, Tamarak and Willow were present in the spill area in 1977.

Sample analysis (Table 7) showed that within the original spill area the concentration of soluble salts at the surface had been reduced to moderately low levels except in the vicinity of soil sample A and water sample # 5. The concentration of chloride had risen to 372 ppm in the small lake while a small reduction in sodium to 65.5 ppm had occurred.

Concentrations of salt around the oil spill had increased over last year. This might have resulted from additional leaching from the battery site or possibly reflect the drying trend that has been evident in the oil spill site over the last two years.

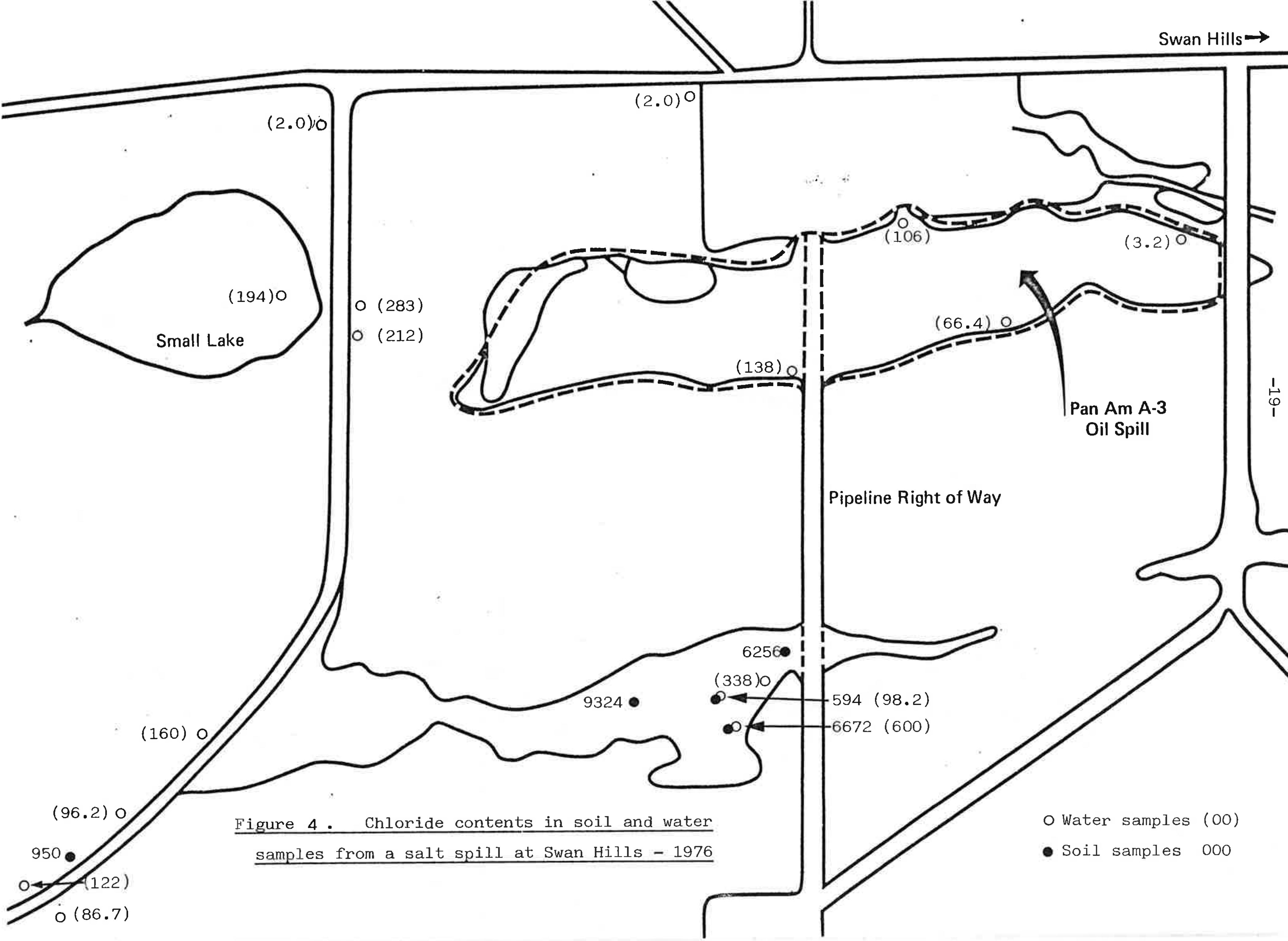

Figure 4. Chloride contents in soil and water samples from a salt spill at Swan Hills - 1976

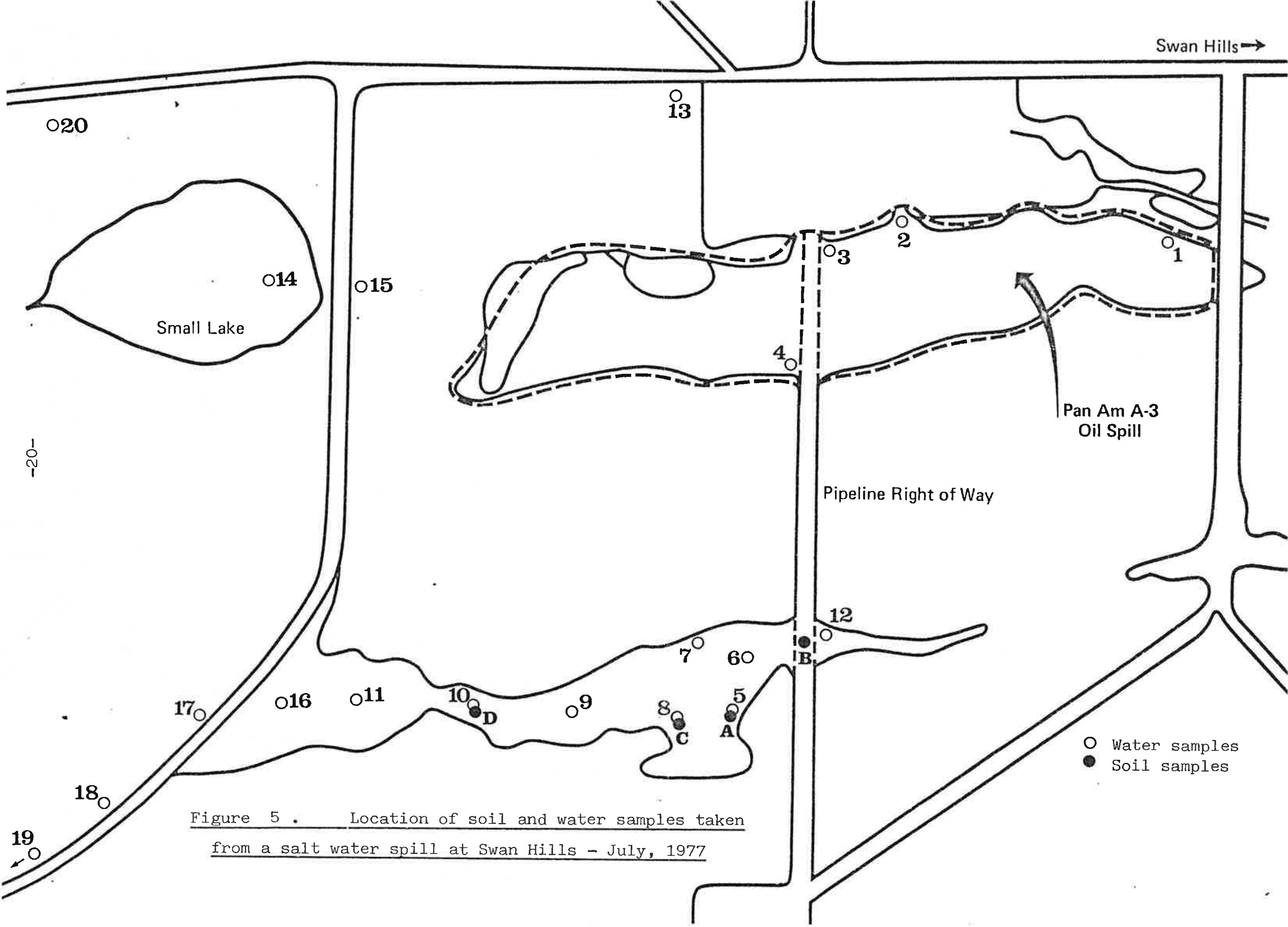

Figure 5 . Location of soil and water samples taken from a salt water spill at Swan Hills - July, 1977

Table 7. Analysis of soil and water samples from a salt spill at Swan Hills, Alberta - July, 1977.

Sample	pH	Cond. (mmhos/cm)	Chloride (ppm)	Sodium (ppm)
Water samples:				
1	6.15	0.028	28.4	1.9
2	5.55	0.37	479	68.3
3	4.55	0.53	851	73.8
4	4.95	0.10	135	3.8
5	6.20	1.45	2390	211
6	5.70	0.15	213	31.8
7	5.20	0.08	92.2	15.8
8	5.10	0.22	131	15.8
9	5.10	0.13	174	6.5
10	4.25	0.13	160	28.0
11	4.50	0.17	125	35.5
12	4.70	0.16	3.5	1.3
13	5.35	0.16	3.5	1.6
14	4.90	0.28	372	65.5
15	5.20	0.32	425	71.5
16	5.20	0.16	167	26.5
17	5.35	0.12	103	24.8
18	5.95	0.11	103	21.8
19	6.50	0.046	3.5	1.9
20	6.70	0.046	3.5	1.6
Soil samples (0-15 cm)				
A	5.25	1.16	4467	2781
B	4.85	1.04	1282	1225
C	4.90	0.39	401	800
D	4.20	0.18	801	644

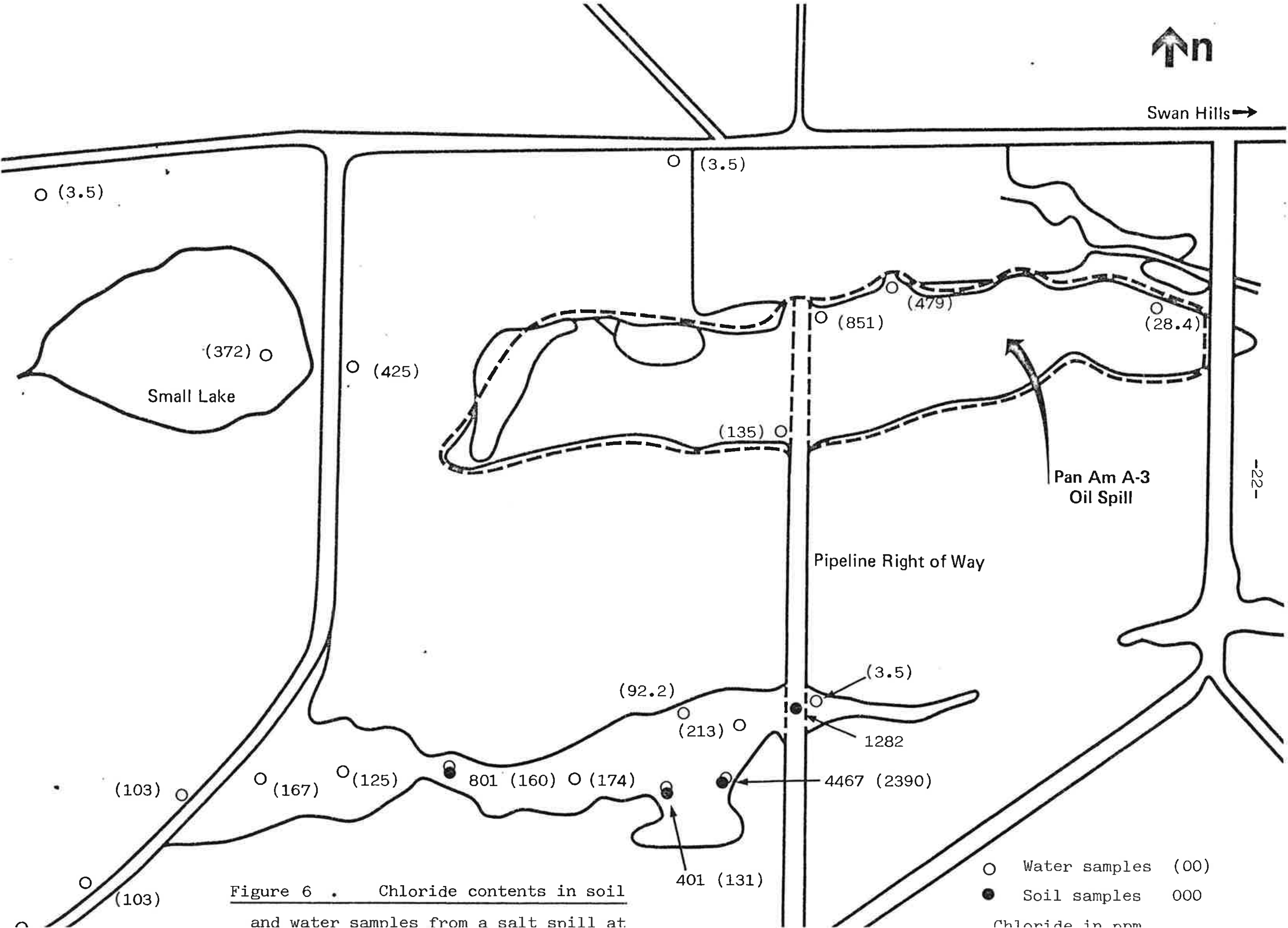

Figure 6 . Chloride contents in soil and water samples from a salt spill at

Analysis of plant samples taken from newly revegetated areas of the salt spilled revealed a wide variation in contents of water soluble sodium and chloride (see Table 8). Some plants accumulated both sodium and chloride in approximately equimolar concentrations while others only accumulated the chloride anion. The Marsh Ragwort (Senecio palustris) grew well in very salty areas and accumulated 61,144 ppm of chloride and 41,563 ppm of sodium in the sample that was analyzed. The Common Cattail (Typha latifolia) accumulated chloride (29,746 ppm chloride) but contained less water soluble sodium (5813 ppm). Slough Grass (Beckmannia syzigachne) flourished on the hitherto barren areas and contained high concentrations of both sodium and chloride. More salt accumulated in the aboveground tissues than in the roots. One sample of Fireweed (Epilobium angustifolium) growing on the salt spill contained 7294 ppm chloride but only 161 ppm of sodium. Another sample taken from an uncontaminated roadside area contained 1683 ppm of chloride and a similarly low amount of sodium (90 ppm).

Some samples of Black Spruce (Picea mariana) taken in 1975 showed that magenta colored needles contained 1800 ppm of chloride while apparently healthy needles contained 200 ppm of chloride. A similar pattern was shown in samples of White Spruce (Picea glauca). In addition, White Spruce seemed to be able to exclude sodium to a certain extent since the concentrations in salt spill samples and those from a control area were both quite low.

Accumulation of sodium with the exclusion of chloride did not seem to occur. One sample of Sphagnum Moss from the spill site did contain more sodium than chloride but the tissues had been washed proir to grinding to remove any entrapped water. It was likely that some cell-bound chloride was lost in this process.

Table 8. Water soluble sodium and chloride in various plant species

Plant type	Location	Chloride (ppm)	Sodium (ppm)
Slough grass (*Beckmannia syzigachne*)	Salt spill		
Tops		8313	6531
Roots		3325	3416
Marsh Ragwort (*Senecio palustris*)	Salt spill	61144	41563
Common Cattail (*Typha latifolia*)	Salt spill	29746	5813
Tamarak (*Larix laricina*) - needles	Salt spill	2944	134
Unidentified *Agrostis sp.*	Salt spill	7010	2594
Carex aquatilis	Salt spill	3806	254
Sphagnum sp. (washed)	Salt spill	341	1775
Fireweed (*Epilobium angustifolium*)	Salt spill	7294	161
	Control	1683	90
Black Spruce (*Picea mariana*)	Salt spill	1800	
	Control	200	
White Spruce (*Picea glauca*)	Salt spill	1022	116
	Control	80	78
Salix sp.	Salt spill	2164	70

4. CONCLUSIONS

The precise time of the salt spill studied here is not known but it probably happened about 2-3 years prior to the first visit to the site in 1975. Considerable damage to the vegetation occurred as a direct result of the high salt concentration. Natural leaching from rainfall (about 20-25 inches per anum) has reduced the concentration of salt at the soil surface to levels that have allowed most of the affected area to revegetate again. Concentrations of soluble sodium and chloride can be expected to be above normal for many years yet. However, the area can be considered to have almost completely recovered from the contamination without suffering any serious after effects. Had more drastic reclamation measures been undertaken, considerably more damage to the area may have been produced.

Increases in chloride and to a lesser extent sodium have been noted in drainage waters up to about one mile from the spill. The levels attained do not represent a serious threat to water quality in the area.

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The studies carried out in 1975 and 1976 formed two consultants reports. We greatly appreciate the cooperation of Federated Pipe Lines Ltd. and Home Oil Company Ltd. in allowing us to present this paper.

PAPER

-3-

THE INTERACTION OF GROUND WATER AND SURFACE MATERIALS IN MINE RECLAMATION [1]

- by -

P.L. Hall, M. Sc., P. Geol.[2]

ABSTRACT

Ground water conditions are frequently overlooked when placing surface materials in a mine reclamation scheme. The purpose of this paper is to outline the interaction between the surface materials and ground water conditions at a mine site. By careful selection and placement of surface materials, it may be possible to minimize adverse impacts on the ground-water regime. Similarly the chances of successful replacement of surface materials may be enhanced by consideration of ground water conditions.

Effects on the ground-water regime will depend upon the placement of surface materials within the ground-water flow system.

Surface materials placed over recharge zones may alter the rate and quality of water infiltrating to the water table. In turn these effects may be reflected in changes in flow and water quality in springs and streams.

The effects of placing surface materials over ground water discharge areas are generally not so widespread. Medium and high permeability surface materials will generally allow ground water discharge to reach the ground surface. Soluble salts may be precipitated if the concentration in the ground water is high enough. These conditions may restrict the type of vegetation which could grow on the surface materials.

Placing low-permeability materials over a discharge area could result in quicking conditions or unstable slopes if the discharge zone occurs on a hillside.

By evaluating ground-water conditions before placing surface materials, it is possible to avoid may of the problems outlined above.

1. Presented at the Canadian Land Reclamation Meeting Edmonton, Alberta, August 18, 1977.

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1.0 INTRODUCTION

The ground water regime forms an integral part of the hydrologic cycle (Figure 1). Precipitation falling on the ground may seep into the ground and become part of the ground water system, alternatively the water may flow over the ground as surface runoff or it may return back to the atmosphere by evaporation. Surface materials replaced during mine reclamation are placed at a critical interface in the hydrologic system (Figure 2). The method of placement and type of surface materials used in mine reclamation can drastically change the volume of surface runoff and the amount of water seeping into the ground.

The effects of surface materials on the ground water regime may best be understood after briefly considering some of the factors controlling ground water movement.

The water table beneath the ground surface is generally a subdued reflection of the topography. Water tends to move from areas of higher potential (i.e. elevation) to ones of lower potential. The relationship of ground water flow lines to topography is shown schematically in Figure 3. Changes in the subsurface geology can

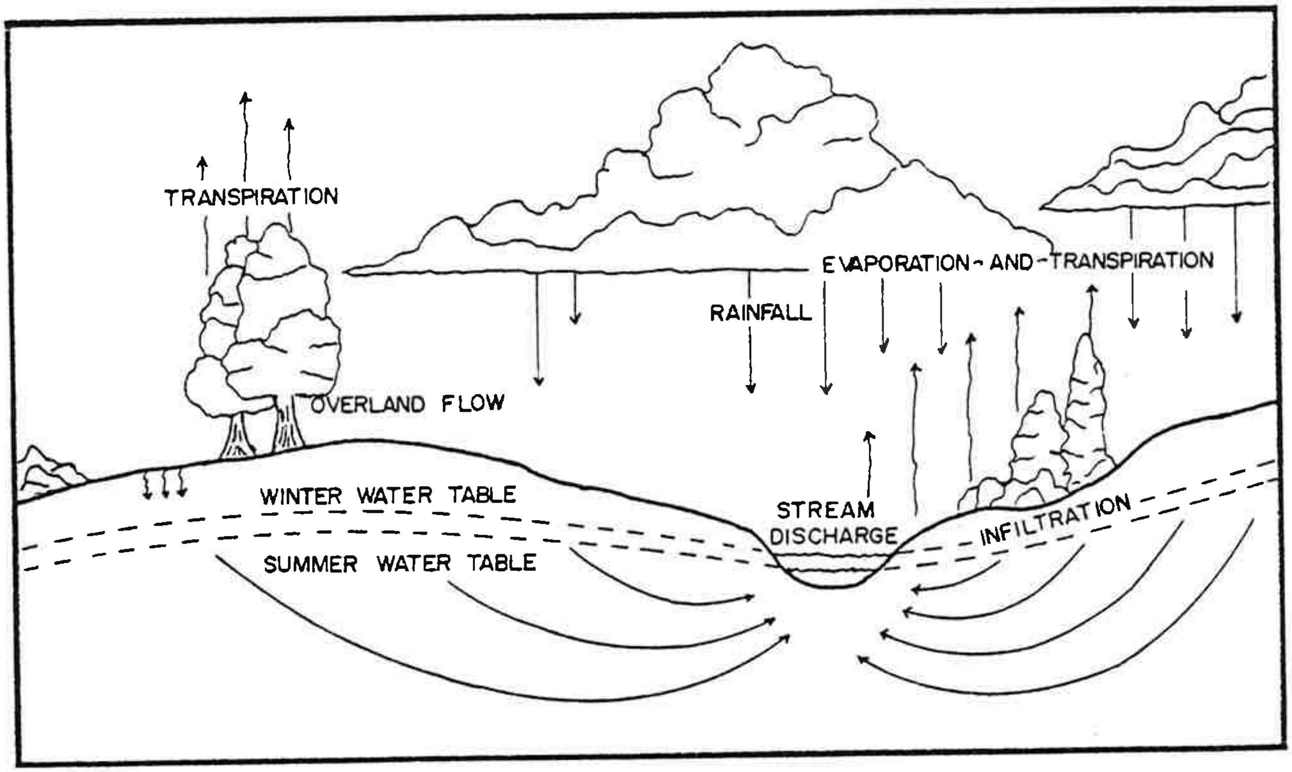

Figure 1 THE HYDROLOGIC CYCLE

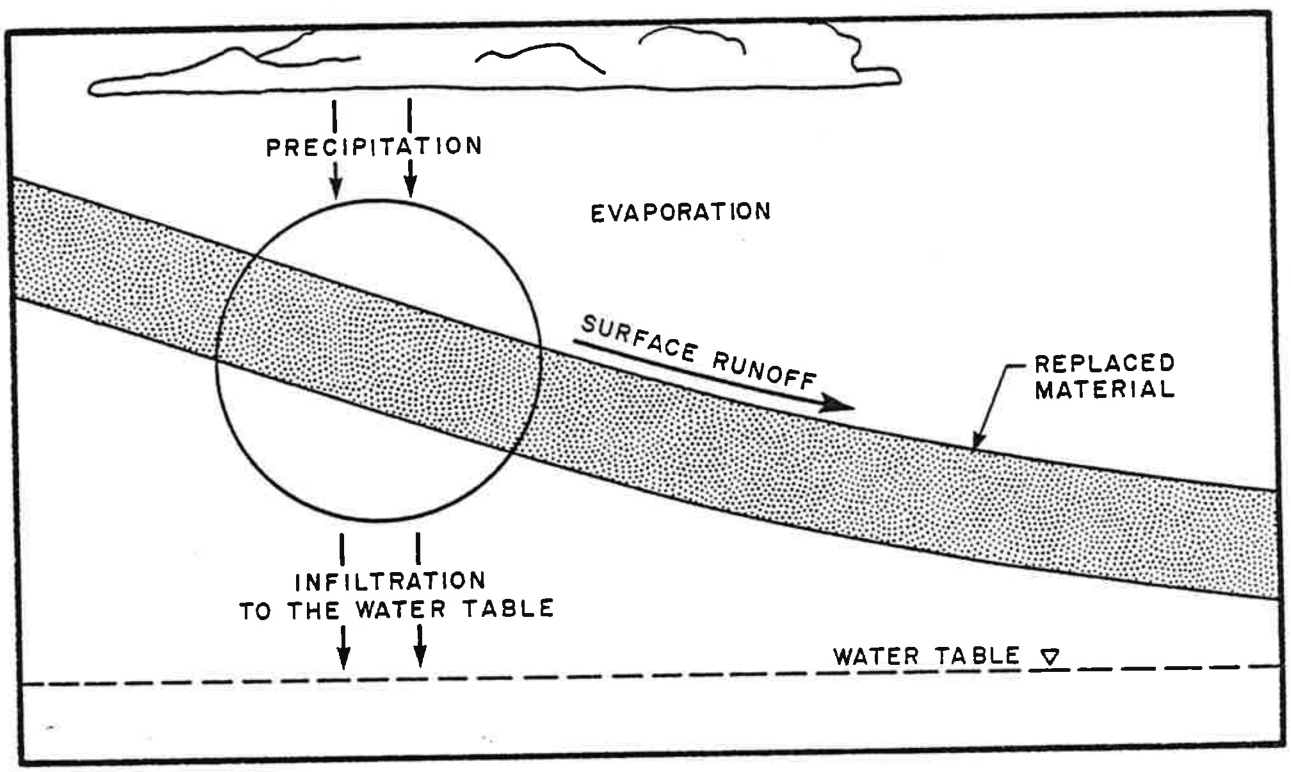

Figure 2 SCHEMATIC DIAGRAM SHOWING THE PLACEMENT OF RECLAIMED MATERIAL AT THE LAND/AIR INTERFACE OF THE HYDROLOGIC CYCLE.

modify these flow patterns considerably. There are two important areas which should be considered separately. The first is a recharge area where water infiltrating down from the ground surface replenishes the ground water system. Such an area has decreasing hydraulic heads with depth, i.e. deeper wells tend to have lower water levels. Ground water discharge areas occur at the other end of the ground water flow system where ground water discharges naturally at the ground surface. They are frequently characterized by springs, marshes or salt residue remaining after the evaporation of ground water.

Recharge and discharge areas are two extremes when considering the impact on the ground water system of placing surface materials. Because of this they will be considered separately.

1.1 Recharge Areas

Land reclamation over recharge zones may modify both the quality and quantity of water infiltrating through the soil to the water table.

Changes in water quality may be brought about by the type of surface material used for reclamation. Even if the material used is the same

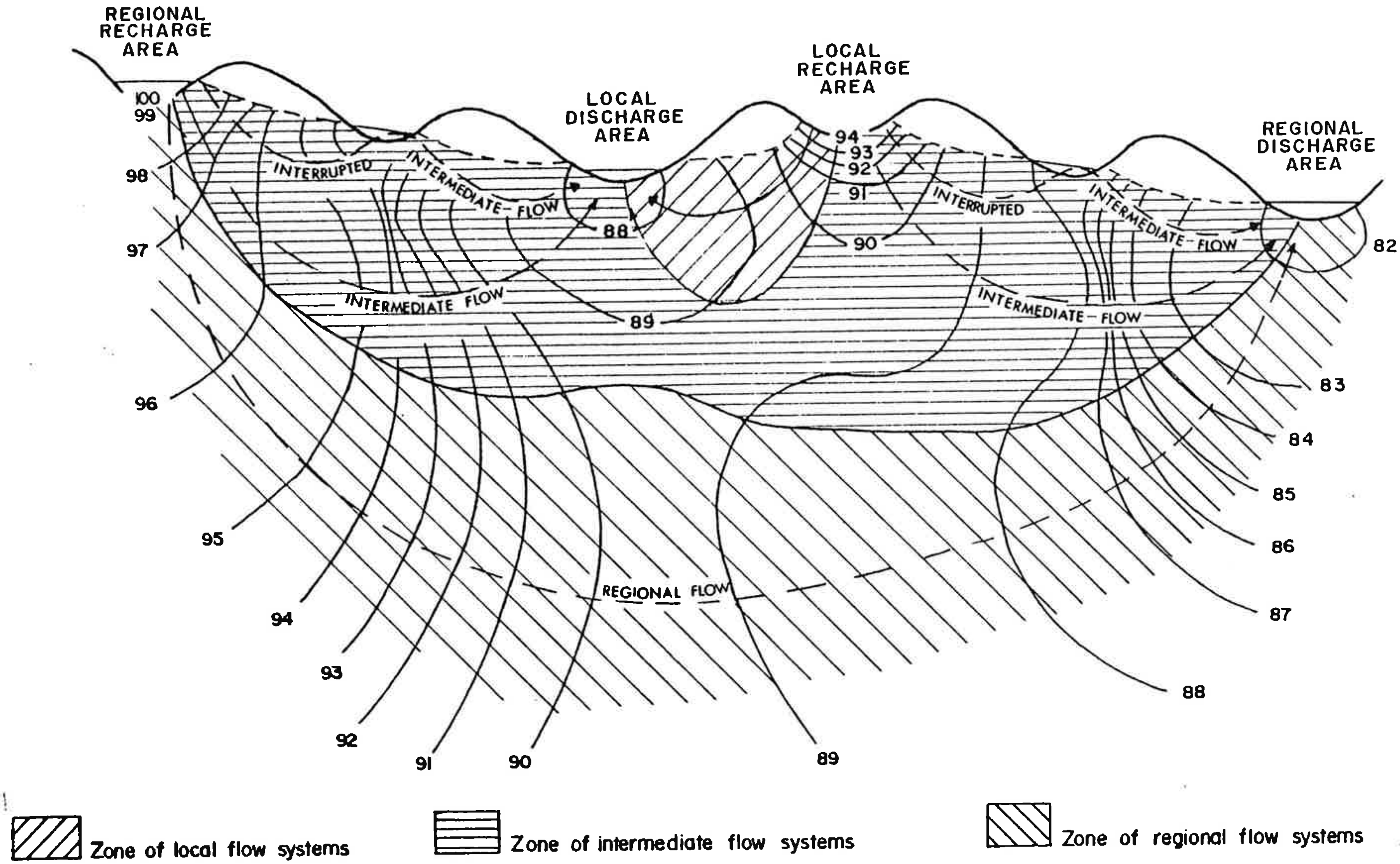

Figure 3 TYPES OF NATURAL FLOW SYSTEMS
(after Lissey, 1972)

as the natural soil cover there may be changes in the amount of soluble material absorbed by the infiltrating water. This can be brought about by the increase in the contact area brought about by decreased compaction or by the alteration of minerals by the oxidation-reduction processes. These changes in sub-surface-water chemistry are discussed in detail in the next paper, presented by Moran and Cherry.

Changes in ground water quality can have both direct and indirect changes on other environmental parameters, as shown in Figure 4. While the changes in ground water chemistry are implemented at a recharge area, many of the impacts may not be noticed until they move through the ground-water flow system.

Changes in ground water quality would readily be noticed in nearby springs, while changes in the water quality of streams and lakes will depend unpon the percentage of the surface water derived from ground water sources and the concentration of the chemical constituents in question. If the total dissolved solids are significantly increased at the recharge area then there may be increased precipitation of salts in

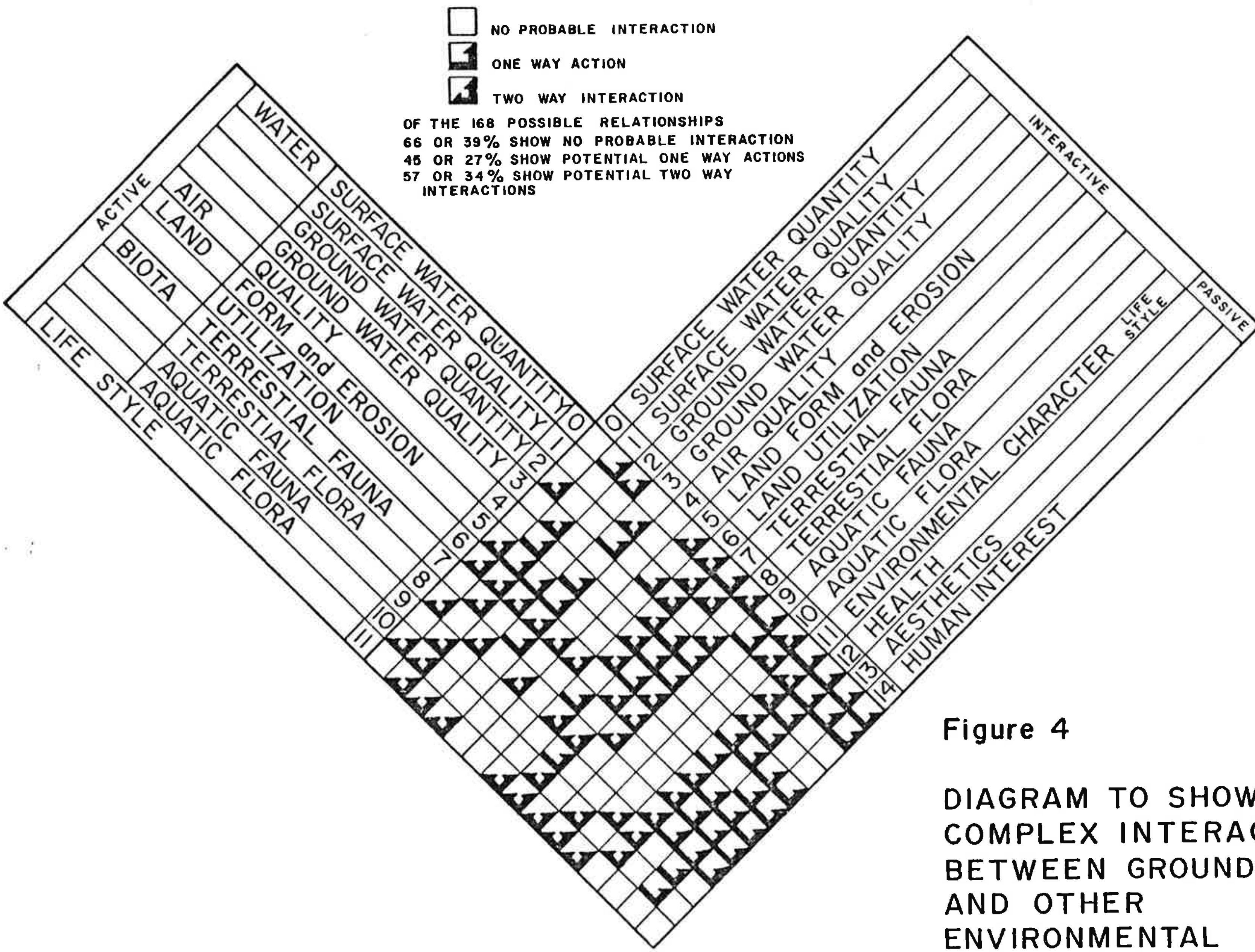

Figure 4

DIAGRAM TO SHOW THE COMPLEX INTERACTIONS BETWEEN GROUND-WATER AND OTHER ENVIRONMENTAL PARAMETERS discharge areas, possibly making land unsuitable for certain crops. Where ground waters are used for irrigation or stock watering, adverse changes in chemistry may require water treatment before use, as might ground water used for human consumption. In general these effects are likely to be more significant where the ground water quality is already marginal or where there is a possibility introducing minor chemical constituents which are toxic at low levels. For example drinking waters with arsenic levels exceeding 0.05 mg/l are unsuitable (Canadian Drinking Water Standards and Objectives, Anon., 1968). Examples of some of these levels are shown in Table I. The impact of chemical changes is likely to decrease away from the reclamation area due to dilution resulting from dispension and diffusion.

Changes in water quantity are generally a result of changes in the infiltration rate. Any increase or decrease from the natural recharge rate will result in changes in the ground water flow system which, in turn,will cause changes in other environmental parameters (Figure 4). When placing

TABLE I CANADIAN DRINKING WATER STANDARDS

TABLE VI

DRINKING WATER STANDARDS FOR TOXIC CHEMICALS*

Toxicant	*Objective* mg/1	*Acceptable Limit*—mg/1	*Maximum Permissible Limit*—mg/1
Arsenic as As	Not Detectable[1]	0.01	0.05
Barium as Ba	Not Detectable	<1.0	1.0
Boron as B	—	<5.0	5.0
Cadmium as Cd	Not Detectable	<0.01	0.01
Chromium as Cr^{VI}	Not Detectable	<0.05	0.05
Cyanide as CN	Not Detectable	0.01	0.20
Lead as Pb	Not Detectable	<0.05	0.05
Nitrate+Nitrite as N	<10.0	<10.0	10.0
Selenium as Se	Not Detectable	<0.01	0.01
Silver as Ag	—	—	0.05

*See Table VII and Table VIII for limits on biocides and other chemicals.

1 Not detachable by the method described in the latest edition of "Standard Methods" (APHA, AWWA, & WPCF), or by any other acceptable method approved by the control agency.

TABLE VIII

RECOMMENDED LIMITS FOR OTHER CHEMICALS IN DRINKING WATER

Chemical	Limit — mg/l	
	Objective	*Acceptable*
Alkalinity	(See Section 8.3.2(1))	
Ammonia as N	0.01	0.5
Calcium as Ca	<75	200
Chloride as Cl	<250	250
Copper as Cu	<0.01	1.0
Corrosion and Incrustation	(See Section 8.3.2(3))	
Iron (dissolved) as Fe	<0.05	0.3
Magnesium as Mg	<50	150
Manganese as Mn	<0.01	0.05
Methylene Blue Active Substances	<0.2	0.5
Phenolic Substances as Phenol	Not Detectable[1]	0.002
Phosphates as PO_4 (inorganic)	<0.2	0.2
Total Dissolved Solids	<500	1,000
Total Hardness as $CaCO_3$	<120	See Section 8.3.2(2)
Organics as CCE + CAE[2]	<0.05	0.2
Sulphate as $SO_4^{=}$	<250	500
Sulphide as H_2S	Not Detectable	0.3
Uranyl Ion as UO_2^{++}	<1.0	5.0
Zinc as Zn	<1.0	5.0

1 "Not detectable" by the method described in the latest edition of "Standard Methods" (AWWA, APHA, WPCF) or by any other acceptable method approved by the control agency.

2 Total of carbon chloroform and carbon alcohol extractibles.

3 Based on taste and odour considerations. Concentration greater than 0.05 mg/l may be objected to by the majority.

surface materials in a reclamation scheme any change in the infiltration rate will result in the opposite reaction from surface runoff. Table II illustrates how various factors related to the placement of surface materials may vary the rates of infiltration and surface runoff.

If the rate of infiltration is decreased and there results in a corresponding increase in surface runoff then the following effects may occur in the surface water system:

(a) Higher peak flows due to the more rapid runoff and loss of temporary storage in the ground water system.

(b) Lower "low flows" due to decreased storage from the ground water system.

(c) Increased erosion and sediment loads.

All three of these factors tend to decrease water resources potential.

The effects of decreased infiltration on the ground water system revolve around the lowering of the water table as evidenced by falling water levels in surrounding wells. Spring flows may decrease and stream flows become significantly

TABLE II

SUMMARY OF

SURFACE MATERIAL PARAMETERS

INFLUENCING GROUND WATER RECHARGE

Parameter	Ground Water Recharge	Surface Run Off
Slope - increase	decrease	increase
- decrease	increase	decrease
Compaction		
- increase	decrease (may reduce soluble material reaching water table)	increase
- decrease	increase (may increase soluble material reaching water table)	decrease
Material		
- increase permeability	increase	decrease
- decrease permeability	decrease	increase
Vegetation Cover	(may increase recharge by reducing run off or decrease recharge by increasing evapo-transpiration)	decrease

smaller during periods of low flow because ground water baseflow frequently makes up a large percentage of stream flow during these periods. Phreatophytic plants drawing their water supply from the water table may die if the water table falls significantly. A chain reaction could be started from the destruction of the vegetation cover which may start with increased erosion causing higher silt loads.

On the positive side, the lowering of the water table may result in the drainage of marsh or swamp land.

When the rate of infiltration is increased the volume and rate of surface runoff is generally decreased. This results in lower peak flows and increased ground water storage raises the low flow levels. Erosion will probably be decreased and the water resources potential will be enhanced.

Raising the water table could pose problems for areas where it is close to ground level. In such areas plant roots may be damaged and low-lying areas may become submerged. Because ground water movement is very slow these phenomena are more likely to occur within or adjacent to the reclamation area.

1.2 Ground Water Discharge Areas

Placement of materials over ground water discharge areas will have less widespread environmental effects than the placement of materials over recharge areas.

If the surface materials are to be successfully revegetated then ground water must be allowed to discharge freely from the underlying materials. If the discharging waters are high in total dissolved solids then there may be excessive precipitation of salts in the replaced material, brought about by evaportation. If this is likely to be a problem then the reclaimed materials should be thick enough to allow drainage of the ground water before it can evaporate. Drainage can be enhanced by placing a more permeable material first which would then act as a natural drain.

Engineering problems may result when the reclaimed surface materials become saturated and slopes become unstable. This may occur in materials of low permeability as they do not allow adequate drainage, more permeable materials may become saturate as well if their placement is such that ground water is impounded within the material because of inadequate drainage.

These problems can be solved by careful selection and placement of materials. Contouring can also enhance drainage and prevent accumulation of ground water in depressions. Vegetation should be selected to be compatible both with the proximatey of the water table and the quality of the ground water.

2.0 SUMMARY

The ground water system can be modified by the placement of surface materials in reclamation schemes. Both the quality and quantity of ground water may be altered and these changes may be noticed well outside the area being reclaimed. Within the area being rehabilitated ground water conditions may influence revegetation plans, create areas of poor drainage and possibly result in slope stability problems.

The first stage in developing solutions to these problems is to identify baseline ground water conditions and to place the area in the correct regional hydrogeological perspective.

Ground water baseline studies are now an integral part of the license application procedure in Alberta and involve the collection and evaluation of existing data. Additional ground water information is frequently obtained from core holes and other test holes. From this information ground water flow patterns may be determined and flow rates calculated.

Recharge and discharge areas can be identified and guidelines can be developed for the type of material and method of placement in the reclamation scheme.

The importance of ground water in the reclamation scheme will be site specific as will be the solution to any problems arising from the interaction of surface materials and the ground water system.

PAPER

-4-

Paper No. 4

Author(s): Stephen R. Moran and John A. Cherry

Title of Paper: "Subsurface-Water Chemistry in Mined-Land Reclamation: Key to Development of a Productive Post-Mining Landscape"

ABSTRACT

The overburden above most of the surface-mineable coal in the prairies of western North America is generally fine-grained, slightly fractured to unfractured silt and clay with sand present in some places. These sediments range from non-calcareous to highly calcareous but are generally slightly calcareous. Pyrite is a common constituent of the silt and clay. Sodium montmorillonite is the dominant clay mineral in much of the overburden.

The distribution of materials results in a groundwater regime characterized by a generally sluggish flow system with infrequent recharge and slow flow velocity. As a result, even at shallow depths, the brackish groundwater is generally characterized by slightly basic pH and the dominant ions Na^+, HCO_3^-, and SO_4^{2-}. This chemistry results from the addition of Ca^{2+}, Mg^{2+}, and HCO_3^- by the dissolution of calcite and dolomite. Na^+ from clay minerals replaces Ca^{2+} and, to a lesser extent, Mg^{2+} by ion exchange producing a further dissolution of carbonate minerals resulting in an increase in HCO_3^- and pH. SO_4^{2-} ions, which are derived through oxidation of pyrite at or near the land surface, are generally precipitated as gypsum, under the semi-arid climate of the region. During the infrequent recharge events the gypsum is dissolved and carried into the groundwater.

Because of the sluggishness of the flow system, few pore volumes of water move through the material in any given time. As a result, the small amounts of slightly soluble calcite and dolomite that are generally present persist and continue to buffer the acidity produced by the oxidation of pyrite. Exchangeable sodium persists relatively close to the surface.

In places where more permeable sand overlies the coal, the greater flushing that is a consequence of the more frequent recharge can result in leaching of carbonates and depletion of sodium to a greater depth. The resulting shallow groundwater is less saline, less sodic, and where excess pyrite is present, more acidic.

In reconstructing the landscape during reclamation the sequence and methods of placement of overburden material determine the post-mining subsurface-water chemistry. The type of material at various places in the landscape, especially at and just below the land surface, determines the initial chemistry. The configuration of the land surface and distribution of permeability beneath the surface determine how the chemistry will evolve over time. The configuration of the land surface controls frequency and location of infiltration. The distribution of material beneath the surface determines the rate of subsurface-water flow and thus the degree of flushing of the system. Interaction between the surface configuration and permeability distribution determines the shape of the water table, its proximity to the land surface, and the location and magnitude of groundwater discharge. The developmen of fractures in the cast overburden, as a result of differential settlement, can permit penetration of oxygen deep beneath the surface. The resulting oxidation of large amounts of pyrite can produce, at least initially, very high levels of sulfate and salinit and low values of pH. Bulking of the cast overburden as it is emplaced will result in initially high values of hydraulic conductivity that may decrease over time. This would result in an increasingly sluggish flow system and a tendency for the water table to rise over a period of time.

By designing the placement of materials and configurations of the land surface with these processes in mind, it becomes possib to construct an Engineered Cast-Overburden (ECO) Landscape in which the final groundwater chemistry can be predicted and will remain within the limits necessary for continued productive use of the lan

SUBSURFACE-WATER CHEMISTRY IN MINED-LAND RECLAMATION: KEY TO DEVELOPMENT OF A PRODUCTIVE POST-MINING LANDSCAPE

by
Stephen R. Moran[1] and John A. Cherry[2]

Introduction

This paper presents some preliminary hydrogeochemical concepts for mineland reclamation. These concepts have evolved during three years of research on the geologic, hydrologic and geochemical nature of terrain in areas of existing or proposed coal mining. These studies, which are described by Moran et al (1976) and (1977) focussed on areas in western North Dakota. Although large scale mined-land reclamation activities are not yet underway in this region, it is our belief that considerable insight with regard to favorable aspects of reclamation designs can be derived from consideration of hydrologic and geochemical processes and their effects in the pre-mined landscape. Although our approach has been derived from studies in western North Dakota, similarities in geology and hydrology in other areas in the Great Plains regions suggest that there is potential for application elsewhere in the region.

Two of the major problems associated with the large-scale development of coal resources in the Great Plains region appear to be related to subsurface water.

1) Much of the area underlain by potentially mineable coal is productive agricultural land. The wise use of resources requires that land that is to be mined be returned to an agriculturally productive condition following mining.

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2) Groundwater serves as the principal or sole water suppl in most of the region. There is, therefore, a concern that a suitable water supply be available following mining to permit re-establishment of an agricultural economy. Actual destruction of aquifers by mining and degradation of water quality as a result of salts generated from spoil material are two problems posed by mining.

Both of these problems related to coal mining are, to a grea or lesser extent, a function of the chemistry of the water in pores in the rock and sediment. Whether in unmined areas or in strip-mine spoil, the chemistry of subsurface water is determined by the climate, the amount, frequency, and timing of precipitation, geology, the texture and mineralogy of the material beneath the surface, and the morphology, the nature and degree of integration of drainage nets. In this report we explore each of these factors and how they interact to determine the chemistry of subsurface wate in the region. From this background we go on to discuss some concepts regarding design of post-mining landscapes that should minimize the development of subsurface waters with adverse salinity that can cause soil conditions deleterious to plant growth.

Geological Settings of Coal Resources in Interior Plains

The vast reserves of lignite and subbituminous coal that underlie extensive areas of the prairies of the United States and Canada were formed during the Cretaceous and Early Teritary Periods from organic matter deposited on the debris washed eastward from the rising Rocky Mountains. As low gradient rivers meandered over their broad floodplains carrying sediment farther and farther eastward, the ocean margin retreated towards the east. From time to time, the supply of sediment diminished or the rate of subsidence increased and the sea spread several hundred miles back over the newly deposited wedge of continental sediment. These marine transgressions became less frequent and less extensive as the Cretaceous period drew to a close about 70,000,000 years ago. The final transgression, which occurred in the Paleocene Epoch about 60,000,000 years ago, extended only to the western edge of North Dakota.

Most of the coal appears to have been deposited in floodplain marshes (Jacob 1972, 1973, Hemish, 1975, Royse, 1967). The floodplain environment was characterized by broad low areas along meandering rivers. Flanking the channels on both sides were raised levees composed of sediment that was dropped as the rivers left their banks during flood stage. Farther out from the channel were the flood basin flats where the fine-grained suspended load was deposited. Swamps and forests, which later formed the coal deposits, were located on the levees and flood basins. The upper part of the levees was characterized by coarser sediment, which,combined with their high topographic position, resulted in low water table much of the time and a predominance of oxidizing conditions. Preservation of organic matter was, therefore, not as common as lower in the landscape. The flood basins were characterized by fine-grained sediment and low topographic position, which combined to produce a high water table. In addition, many areas would hold water for extended periods of time following flood events. The net result of this was reducing conditions in which excellent preservation of vegetative matter occurred. However, because of the frequent and extended flooding, growth of vegetation was not as great in the flood basin as on the somewhat higher and drier lower part of the levees.

These environmental controls resulted in four distinct types of sedimentary sequences within the floodplain setting.

1) Areas that were dominantly channel, contain considerable sand, generally from medium to very fine grained. In some places, the sand is well sorted but it is generally poorly sorted. Coarse to medium silt of the upper levee is commonly interbedded with the coarser sediment. The sediment is generally oxidized. Coal beds are not common with only the thicker, more important coals present (Fig. 1).

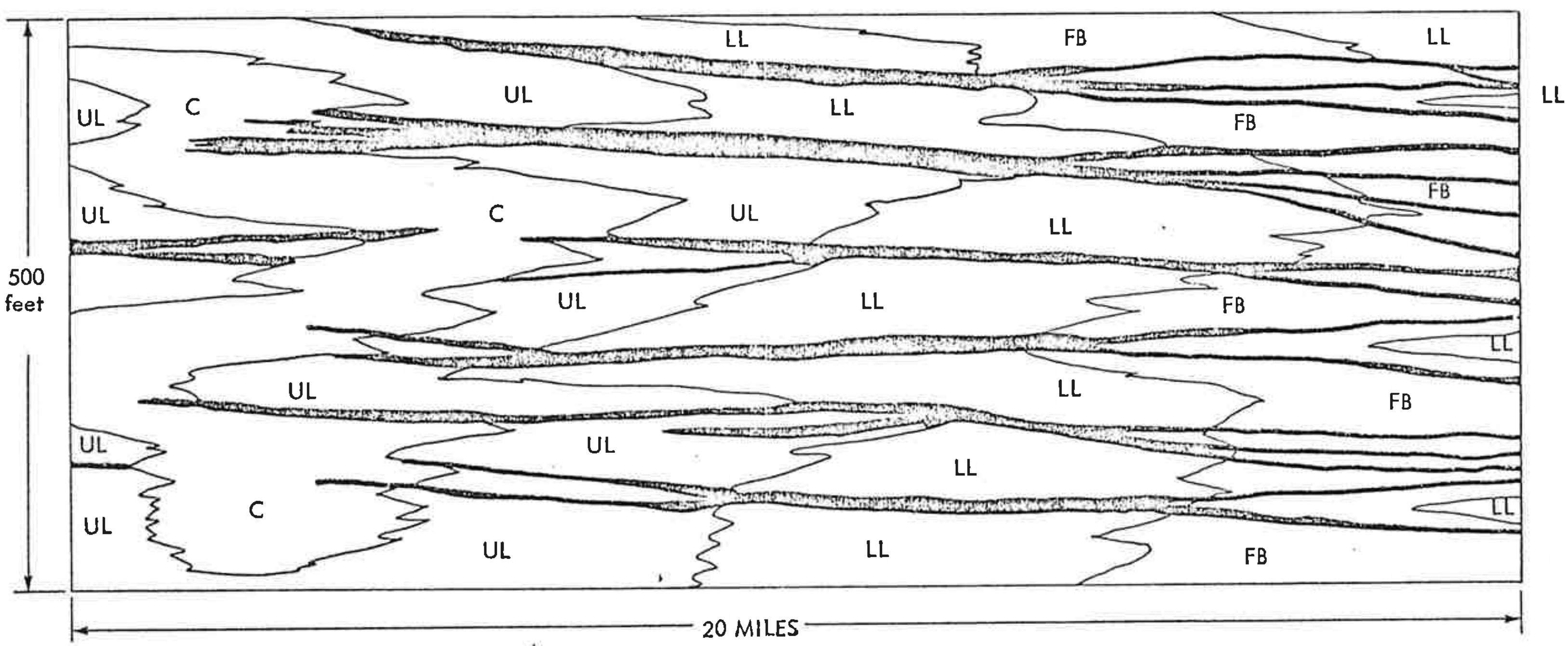

Figure 1. Schematic cross-section showing distribution of coal beds in a typical floodplain sequence. Channel sediment (C) grades laterally into the upper levee (UL) and then the lower levee (LL), which grades out into the flood basin (FB).

2) The upper levee environment produced sedimentary sequences composed predominantly of thick beds of coarse to medium silt with interbeds of poorly sorted fine to very fine-grained sand. The sediment is generally oxidized. Although more abundant than in the channel environment, coal beds are few with only the major beds being present. Beds of coal only a few centimetres thick, which thicken away from the channel are also present (Fig. 1).

3) The lower levee environment is characterized by fine-grained silt with interbeds of coarse silt and clay. Beds of poorly sorted, fine-grained sand are rare. Coal beds are thick and abundant. Partings tend to be thin. Oxidized and unoxidized sediment is interbedded in this environment (Fig. 1).

4) The flood-basin environment is characterized by thinly bedded clay and medium-to fine-grained silt. Poorly sorted, fine-grained sand rarely is present. The sediment is generally unoxidized. Coal beds are abundant but generally tend to be thin (Fig. 1).

As a consequence of these environmental and sedimentological variations within the floodplain environment the original distribution of mineral species varies. The parent material from which most of the sediment was derived was early and middle Mesozoic and upper Paleozoic sedimentary rock. Active volcanoes to the west provided a significant component of the sediment. Carbonate minerals, dominantly calcite, are generally most abundant in the very fine sand and silt sizes. Therefore, sediment of the channel and especially the levee contains calcareous material. The finer grained sediment of the flood-basin generally contains less calcite. Because of the fine grain size of the flood-basin sediment, clay minerals, generally montmorillonite, are most abundant here. The origin of the sodium, which is the dominant exchangeable cation on the clay minerals in most areas, is not understood. Possible sources include sodic volcanic debris, a significant minor constituent of the sediment, and sea water of later marine transgressions over the area. Because of the generally reducing conditions of the flood-basin environment, pyrite is more abundant in these sediments than in the coarser grained sediment of the levee and channel, which was deposited under generally oxidizing conditions. Because of the continental setting and apparent humidity of the depositional environment, it seems highly unlikely that any soluble salts were deposited either as detritus or as precipitates from solution.

Many of the areas in the plains that are underlain by coal deposits were either overridden by continental glaciers or experienced drainage modifications as a result of nearby glaciers. Glaciation has had three major effects which influence the hydrological and chemical conditions in these areas.

1) Deeply incised meltwater trenches have been cut across many areas that otherwise would have very low relief. This has resulted in deep hydraulic drains, the Missouri River and other meltwater channels, which produce low groundwater levels and a stro downward component to the hydraulic gradient in these areas.

2) Coarse sand and gravel was deposited in these meltwater trenches in many areas. In some cases, the valleys were filled by glacial sediment during later glacial advances; in other cases not. These valleys, filled with permeable, coarse sand and gravel, serve as drains that intercept water flowing in coal an sand aquifers and drain it out of the system.

3) The glacial sediment, till, that covers many areas, is generally fine-grained and contains a mixed mineralogical and petrological assemblage, much of which is alien to the area where it is found. Dolomite from the lower Paleozoic rocks exposed along the edges of the Canadian Shield is abundant. Kaolinite, chlorite and illite are abundant in the clay mineral assemblages, in addition to the montmorillonite of the local bedrock. The fine grain size and mixed mineralogy makes the glacial sediment a much better source of mineral nutrients than is the local bedrock, resulting in better soils and crop growth in many areas.

Hydrological Setting of Plains Area Coal Deposits

The subsurface hydrologic regime in the plains area of western North Dakota is controlled largely by the climate and the hydraulic conductivity of the rock and sediment. The semi-arid climate of this region results in an excess of evaporation and transportation relative to precipitation. The moisture deficiency combined with the generally fine-grained nature of the rock and sediment results in infrequent, episodic infiltration of water below the soil to produce groundwater recharge.

Although most of the water that falls in these areas evaporates directly or quickly runs off during each precipitation event and during spring snow melt a portion of the water infiltrates into the soil zone. In most landscape settings, this water is completely removed as a result of direct evaporation and transpiration through plants (Fig. 2). In areas of closed depressions and flat areas where the slope decreases abruptly and the drainage area is sufficiently large, runoff is accumulated. Some of these concentrations of runoff are sufficiently large that more water is available to enter the soil than can be removed by evaporation and transpiration. In these places, water infiltrates through the soil into the unsaturated zone beneath (Fig. 2). Once beyond the reach of plant roots the water in the pores is generally not subject to transfer back to the surface.

In areas where the water table is close to the surface, recharge of the groundwater reservoir can occur by the process of direct infiltration described above. More commonly, however, the water table in plains areas is at considerable distance below the surface, commonly several 10's of metres below. In these places, water from a single major infiltration event is insufficient to reach the water table and is stored in the partly saturated pore spaces beneath the soil and above the water table. Renewed downward movement occurs with each major infiltration event.

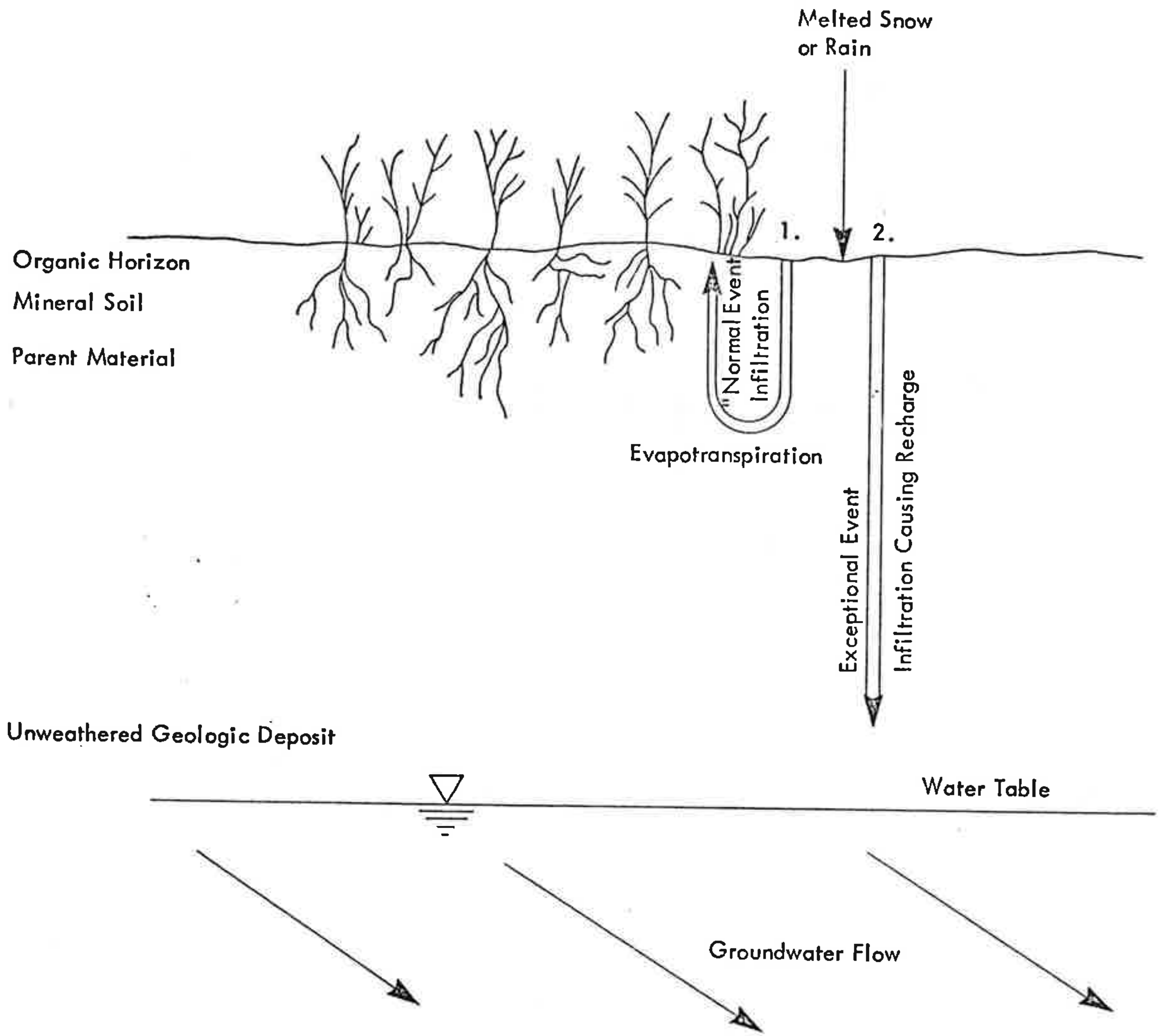

Fig. 2: Schematic Diagram of Subsurface Water Movement in Much of the Plains Region. 1. Annual Potential Evopotranspiration Greatly Exceeds Annual Precipitation, Therefore Infiltration Caused by Most Rainfall and Snowmelt Is Lost by Evopotranspiration. 2. Very Exceptional Events Cause Recharge.

In most of the plains region, groundwater moves downward or laterally (Fig. 3). Areas characterized by upward moving groundwater are of limited extent. Therefore, in most areas, the water then enters the groundwater reservoir by either of the processes outlined above, moves downward and then laterally away from the site of recharge. The rate and direction of groundwater flow is controlled by the magnitude and contrast of hydraulic conductivity of the rock and sediment and by the relief on the water table, which is controlled largely by the topographic relief.

The hydraulic conductivity of the coal and sand aquifers is generally at least 2 to 4 orders of magnitude higher than that of the silt, clay and shale confining beds. This contrast in hydraulic conductivity results in generally downward flow in the fine grained beds and lateral flow in the permeable beds (Fig. 3). Thus, there is a tendency for the water to continue moving downward from the water table until it encounters a permeable bed. The flow then is diverted laterally toward the outcrop of the permeable bed where it is discharged as springs or seeps.

We expect that the principal changes in the hydrologic regime that will be brought about by mining result from the more uniform distribution of hydraulic conductivity in cast overburden relative to the unmined condition. In many areas, the principal permeable beds prior to mining are the coal beds that are removed during mining. As a result, the more highly permeable, laterally continuous drains that can promote lateral flow will generally be absent in the mass of cast overburden. The silt and clay beds, which under natural conditions constitute the low permeability confining beds will be replaced as a blocky fill. The blocky structure of the clay, silt and shale material results in an increase in hydraulic conductivity as water is able to flow around the blocks rather than through the pores. The hydraulic conductivity of this clayey sediment probably decreases with time as the fractures are filled by fine-grained material produced by crushing of the blocky material and by slaking in response to wetting. The harder and more resistant the rock, the slower this process will operate.

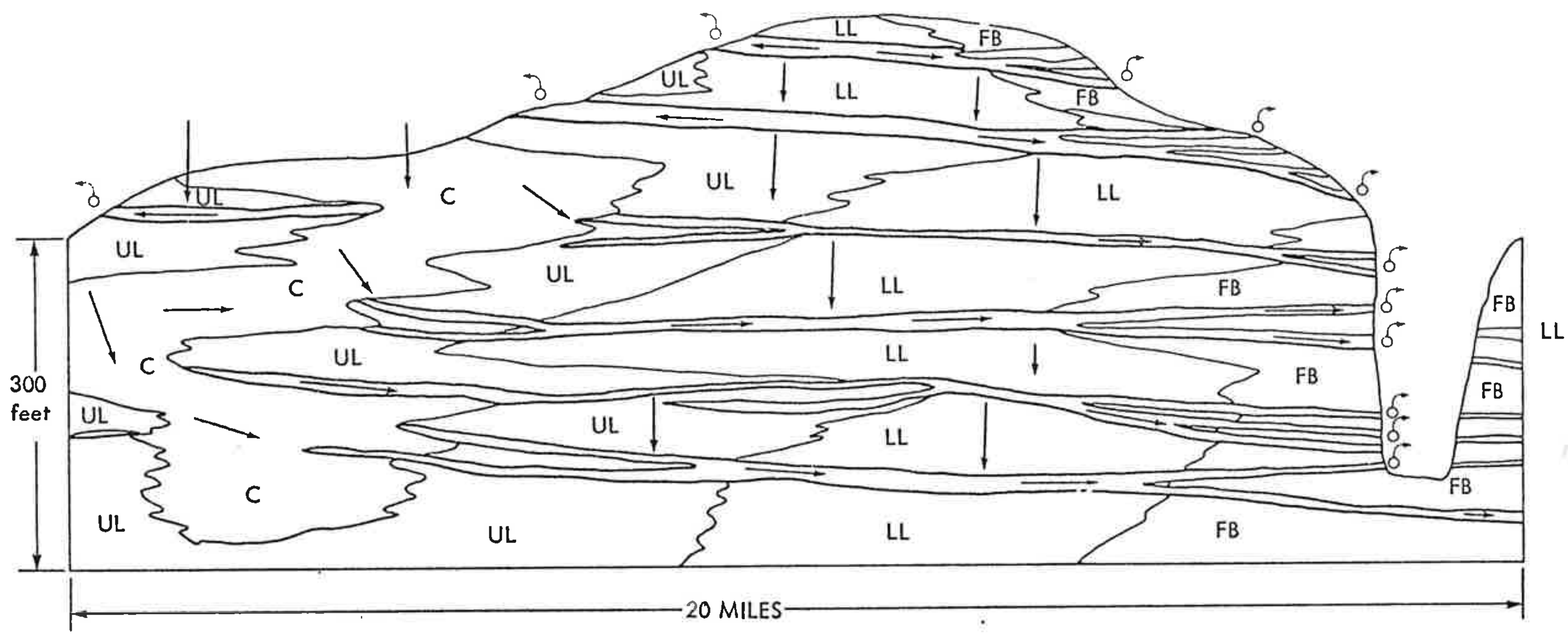

Figure 3. Cross section showing typical pattern of groundwater flow in upland areas of the interior plains where glacial sediment is thin or absent. Permeable coal beds channel groundwater flow laterally to springs and seeps at nearby outcrops.

In some materials, especially sodic clays and shales and materials emplaced in a frozen state, large cracks, which extend to considerable depth, will be opened by differential settling, lateral movement, and expansion and contraction of the cast-overburden mass. These cracks would provide avenues by which water can move quickly from the surface into the groundwater without infiltrating through the soil.

The net effect of these changes is to produce a groundwater-flow system in which flow is more rapid than in the pre-mining state. Flow rates will probably decline with time as the cast overburden consolidates and settles. Except locally, water will penetrate downward to the base of the fill where it will flow laterally out of the excavation through the coal that has been mined. Down gradient from the mine in areas of multiple seams, this may result in shrinkage or disappearance of springs and seeps at the outcrop of coal beds above the base of the excavation. Springs and seeps at the outcrop of the coal at the base of the excavation may increase in size and flow and new ones may develop.

Hydrochemical Setting of Areas of Plains Coal Reserves

In this discussion we describe the chemical evolution of rainfall and snowmelt as it infiltrates and travels through the subsurface. Studies of the chemistry of groundwater in western North Dakota have shown that the geochemical processes that are active in the soil and shallow subsoil control the chemical evolution of subsurface water. Processes that occur below the water table are relatively unimportant. Figure 4 indicates the major geochemical processes that occur in the soil and subsoil as infiltration takes place. The sequence of processes illustrated in this diagram have been grouped according to the nature of the infiltration event. These processes and this effect are described below.

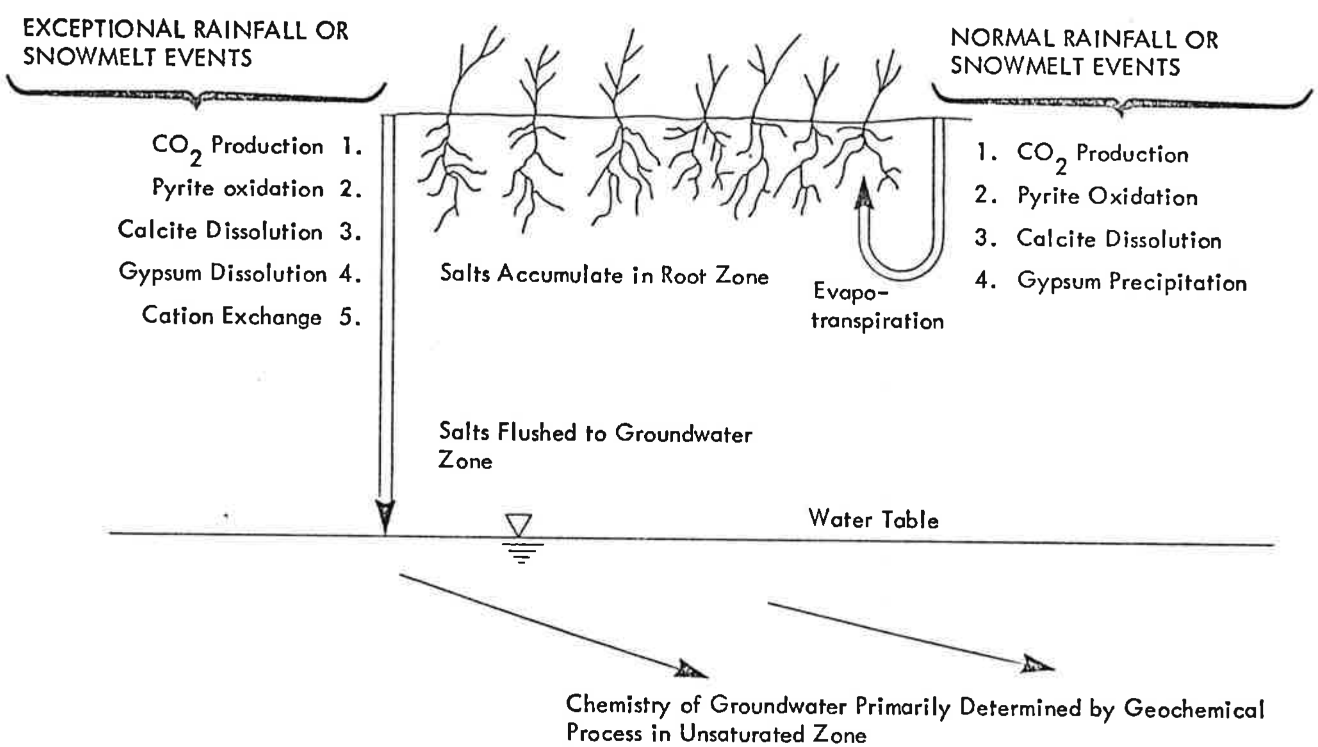

Fig.4 : Schematic diagram of chemical processes and salt movement in much of the plains regions.

Rain and snowmelt has less than 10 to 20 mg/l of total dissolved solids and has a pH of 5 to 6. As it flows on and below the ground surface it acquires much higher contents of dissolved salts and much higher pH. The portion of the rain and snowmelt that infiltrates directly into the soil quickly changes in composition. Biochemical decay of organic matter in the soil generates abundant CO_2 to the soil air and H^+ in the soil water. Oxygen in the soil air and dissolved oxygen in the infiltrating water causes oxidation of pyrite in the mineral soil. This generates H^+ (acidity) and SO_4^{2-}. In the mineral soil, the water dissolves carbonate minerals. As this occurs, the H^+ content in the water decreases (the pH increases) and the HCO_3^-, Ca^{2+} and possibly Mg^{2+} contents increase. Mg^{2+} would be important if dolomite were present. The chemical reactions that represent the processes described above are indicated in Table 1. The processes of CO_2 generation, pyrite oxidation, and carbonate mineral dissolution occur in the soil and in the shallow subsoil, that is, within one or two metres of ground surface. Therefore, pore water that occurs in this zone after rainfall or snowmelt periods is characterizied by Ca^{2+}, HCO_3^-, $SO_4^{2-}$and in dolomitic areas by Mg^{2+}. Because of the infrequency of infiltration events that cause passage of water to the water table (i.e. infrequency of recharge), pore waters that acquire these constituents often undergo concentration as a result of evapotranspiration. This causes precipitation of calcite and gypsum in this shallow zone in which penetration by infiltration is common and in which throughflow is rare. These geochemical processes and the pore water chemistry that results from their activity are summarized in Figure 5.

Gypsum is a key ingredient in the hydrochemical framework. During the very infrequent, but nevertheless geochemically significant, infiltration events that cause throughflow to the water table, gypsum formed during non-throughflow events dissolves. Since gypsum is a moderately soluble salt, dissolution of even small amounts of this mineral causes the water to acquire major concentrations of SO_4^{2-}. Groundwater in the regions under consideration

1/	CO_2 production in organic horizons of the soil $CH_2O + O_2 \longrightarrow CO_2 + H_2O$
2/	Oxidation of pyrite $4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-}$
3/	Dissolution of calcite and dolomite $CaCO_3 + H^+ \longrightarrow Ca^{2+} + HCO_3^-$ $CaMg(CO_3)_2 + 2H^+ \longrightarrow Ca^{2+} + Mg^{2+} + 2HCO_3^-$
4/	Precipitation and dissolution of gypsum $Ca^{2+} + SO_4^{2-} + 2H_2O \longrightarrow CaSO_4 - 2H_2O$
5/	Cation exchange Ca^{2+} + 2Na (adsorbed) $\longrightarrow$ $2Na^+$ + Ca (adsorbed)

Table 1 Chemical representation of major process in the chemical evolution of soil water and groundwater in shallow Tertiary deposits.

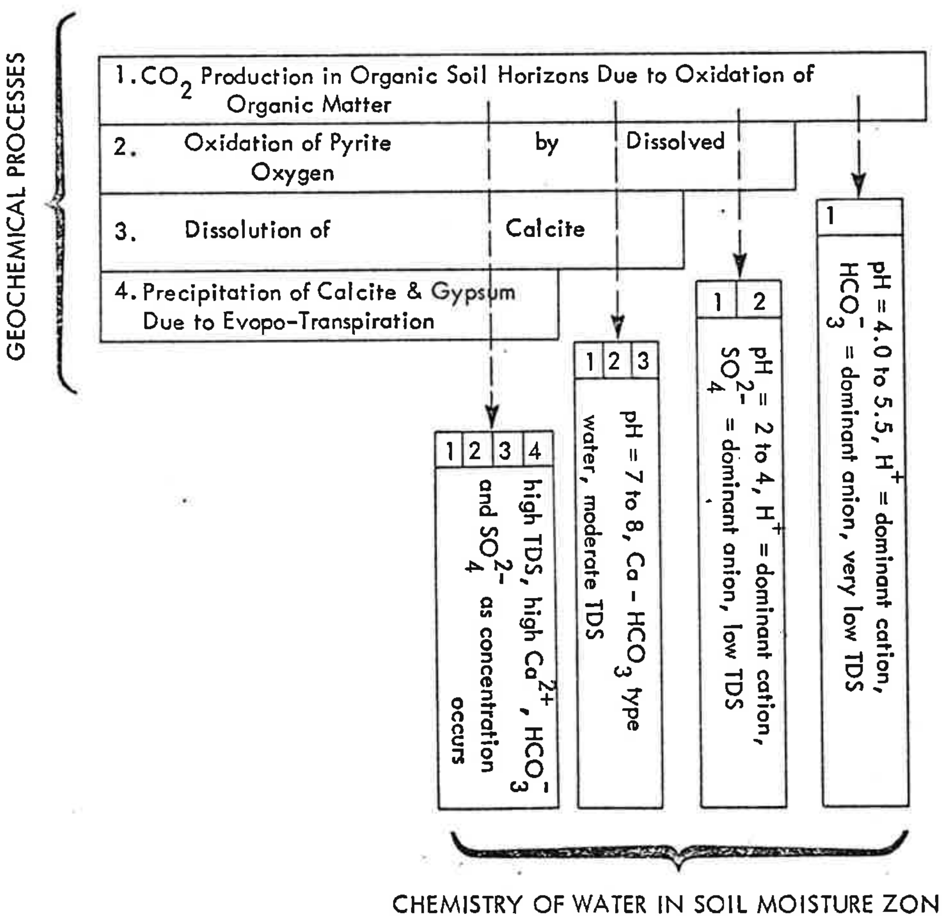

Fig. 5: Diagram illustrating relations between major geochemical processes and water chemistry resulting from infiltration that does not pass below the root zone.

contains Na+ as the dominant cation rather than Ca^{2+}. This is attributed to the process of cation exchange caused by Na-rich clay minerals. The clays provide Na^+ to the pore water if Ca^{2+} is present in the water to serve as an exchange ion. The reservoir of exchangeable Na^+ is gradually depleted as the process occurs through repeated infiltration events, as a result the zone in which the exchange process occurs will migrate deeper with time. The chemistry of shallow groundwater suggests that the exchange process produces Na^+- rich groundwater prior to arrival of the water in the water table zone. Depletion of exchangeable Na^+ in the clayey materials in the zone above the water table may require many tens of thousands of years or longer. The geochemical processes that occur during recharge events and their effects are summarized in Figure 5. For convenience of diagramatic display the processes have been arranged in sequence. In nature, they can occur simultaneously or in sequence depending on the minerology of the materials encountered along the paths of infiltration.

In nature, the above framework of geochemical processes accounts for the occurrence of Na^+ - SO_4^{2-} - HCO_3 rich water as the dominant type of groundwater in the Tertiary deposits of continental origin. It provides an explanation for the occurrence of mobile salts in the subsurface environment. In situations where the salts can accumulate within the root zone, the agricultural productivity of the soil is threatened. This may occur in areas of groundwater discharge and exfiltration as well as in recharge areas as outlined above.

The rate at which gypsum is produced in the soil or subsoil depends on the frequency and magnitude of infiltration events, the amount of pyrite in the soil and subsoil, the extent to which oxygen in the upper part of the soil is consumed by oxidation of organic matter, and the rate of gas diffusion in the soil and subsoil. At present very little is known about the specific nature and interrelations of these factors as they exist under natural conditions. Extension of this interpretive framework to post-mining terrain will remain problematic until appropriate field and laboratory experiments are conducted.

Some of the water that temporarily accumulates in minor depressions may be lost by evaporation, thereby causing concentration of salts in the remaining water than infiltrates. The accumulated water in the depressions would be expected to contain minor amounts of Ca^{2+} and HCO_3^- as a result of dissolution of particulate calcite during runoff, which in some areas involves some degree of surface erosion. If pyrite is encountered by the runoff water, oxidation will produce SO_4^2. If water in the depressions evaporates to dryness, it is reasonable to expect that small amounts of precipitated gypsum and calcite will occur. The calcite is of little consequence because it also occurs in most of the bedrock materials. The gypsum is important because it serves as a Ca^{2+} and SO_4^{2-} source for water than infiltrates during major rainfall and snow melt events. In areas of grassland, it is unlikely that particulate mineral matter occurs in the runoff water to an extent that significantly increases the salt content prior to infiltration in the depressions. In areas of cultivation, and areas of exposed bedrock particulate pyrite as a SO_4^{2-} source in surface runoff is a much more likely possibility.

In situations where Na-rich clays are absent, Ca^{2+}, SO_4^{2-}, and HCO_3^- will be dominant (Fig. 6). In situations where pyrite is absent, water that is much lower in dissolved salts and has dominant concentrations of Na^+ and HCO_3^- will develop. If the soil and subsoil are devoid of calcite and dolomite, the water will become very acidic as a result of SO_4^{2-} production from pyrite and from CO_2 generation. The chemistry of soil water and groundwater in reclaimed land will be governed by the processes indicated in Figures 5 and 6. What is not known, however, is the manner in which the processes will combine and the net result. In the next section we draw attention to some potential manifestations of these processes in areas of reclaimed land.

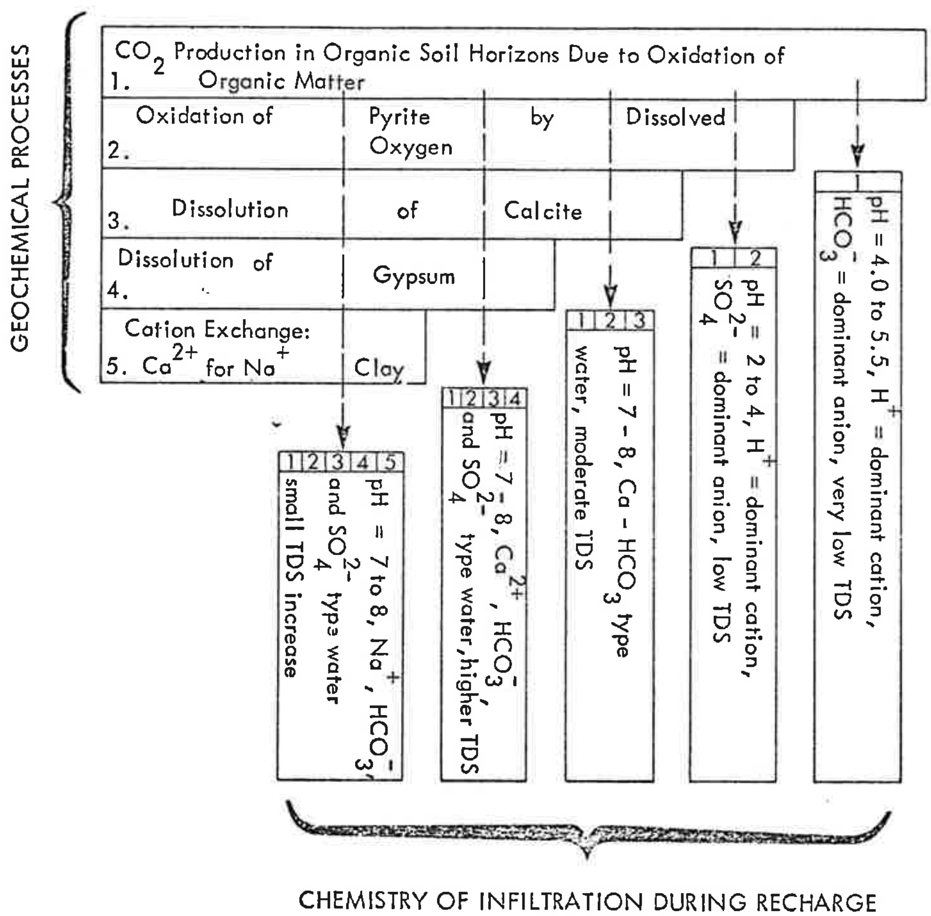

Fig. 6: Diagram illustrating relations between major geochemical processes and water chemistry resulting from infiltration that penetrates below the root zone.

Some Concepts for Mineland Reclamation

In order to reclaim a landscape that is to be disrupted by surface mining so that it continues to be productive on a long-term basis, it is necessary to design the placement of material and the configuration of the land surface so that subsurface-water movement does not cause a progressive, adverse modification of the original chemical profile. In some instances it may even be possible to design the landscape so that the movement of subsurface water over an extended period of time will improve growing conditions. In order to accomplish these objectives, the landscape must be designed for salt management, especially sodium management, and therefore for water management. The first step in this process is to identify the distribution of physical and chemical conditions in the overburden. The second step is to selectively remove and replace the overburden during mining so that materials having desirable properties are at the surface and those with undesirable properties are deeply buried. As a consequence of this process, the distribution of hydraulic conductivity and surface form, which will dictate water movement in the postmining landscape, are established.

In this section we explore some landscape design options that might be used to achieve specific goals. Because of the great complexity of the system being considered here and the obvious need for simplicity in addressing it at this stage, the following discussion will inevitably appear simple minded and naive. This section is intended to communicate an idea, a conceptual approach to reclamation design, not a working design for present reclamation. It is our belief that this approach to landscape reclamation has potential for being useful and that the understanding of landscapes and the hydrology and geochemistry that is needed to implement such an approach, can be obtained through further research, even though much of the necessary knowledge is not currently at hand.

One of the principal differences between productive and non-productive soils in western North Dakota is the balance between physical erosion and salt flushing and accumulation. Non-productive soils occur in two settings. They are developed either on materials that originally contained deleterious materials or on materials into which deleterious materials are transported. In the first case, the rate of flushing of sodium and other salts is slower than is the rate of physical erosion. Thus, unweathered parent material that is laden with deleterious constituents is constantly available in the soil and subsoil zones. In the second case, the rate of accumulation of salts is greater than the rate of removal of material by physical erosion. Productive soils, on the other hand, occur where flushing of deleterious constituents occurs at a rate more rapid than the rate of removal of flushed materials by physical erosion.

On the basis of these ideas it seems reasonable that the greatest potential for optimum agricultural productivity can be obtained if water movement is downward into the ground. The rate of movement through the soil and subsoil must be slow enough that the needs of plants for water can be met yet rapid enough that undersirable salts can be carried away from the surface beyond the reach of roots of transpiring plants. There must be provision for the removal of water from within the cast-overburden mass so that the water table does not rise to high and from the surface of the cast overburden so that erosion of the flushed zone is not too rapid.

These objectives can both be achieved if moderately permeable sandy materials are placed as a layer at the upper part of the cast overburden beneath a veneer of plant growth material (soil and subsoil). The most desirable sand for this purpose is well sorted channel sand, which has low clay and silt content and therefore higher permeability and lower exchangeable Na than the other types of bedrock sediment that occur above the exploitable coal. Based on the interpretive geochemical framework outlined above, emplacement of a few metres of permeable sand beneath the soil veneer would prevent the formation of appreciable amounts of SO_4^{2-} in soil and subsoil water. If SO_4^{2-} production by pyrite oxidation is relatively inactive, and if infiltration passes through the sandy subsoil zone sufficiently frequently to prevent accumulation of gypsum from the small amount of SO_4^{2-} that does occur, the pore water in the soil will be characterized by low dissolved solids. The water will have HCO_3^- as the dominant anion, and will have low contents of Na^+, Ca^{2+}, and Mg^{2+}. Flushing as a result of snowmelt and heavy rainfall will gradually remove exchangeable sodium from the sand, leaving the exchange sites on the clays loaded with Ca^{2+} generated mainly by the dissolution of carbonate materials.

If there is little production of dissolved salts in the subsurface water as it passes through the soil and sandy subsoil, there will be little tendency for extensive saline soil conditions to develop in areas of groundwater discharge. The influx of salt into surface water will also be minimal.

Because of the great abundance of Na-rich, pyritic, fine-grained deposits that will be excavated during mining in most areas, it will be necessary to emplace some of this material below the surface sand in much of the reclaimed landscape. We now examine the potential for salt generation within these materials.

Most of the water that infiltrates below the root zone in the sandy subsoil will eventually move to the base of this deposit where it will flow laterally toward discharge zones or flow into the finer-grained, lower permeability deposits below. The water that moves into the finer-grained, Na-rich, pyritic deposits will remain at low levels of dissolved solids if pyrite oxidation does not occur to a significant extent. Unless the water contains significant concentrations of dissolved oxygen, pyrite oxidation will not be an active process. If significant oxidation does occur, the pore water will acquire additional SO_4^{2-} and H^+. If the sedimentary material is calcareous, the H^+ will be consumed by dissolution of calcite and possibly dolomite. The pore water will contain increased

HCO_3^-, Na^+, and possibly Mg^{2+}. The Na^+ will be contributed to the water from the Na - Ca exchange reaction between the pore fluid and the sodic clay fraction of the sediment. The concentration of SO_4^{2-} will remain very low (below 10 to 20 mg/l) because consumption, through pyrite oxidation, of all of the dissolved oxygen in oxygen saturated water (8 to 11 mg/l of dissolved oxygen) cannot yield much SO_4^{2-} This is evident from Eq. 2 in Table 1. The pore water will probably contain a maximum of several hundred milligrams per litre of Na^+ and between 400 and 800 milligrams per litre of HCO_3^- and only very low concentrations of other cations and anions. Gypsum precipitates will not form because of the paucity of SO_4^{2-} and the absence of the concentration effect caused by evapotranspiration.

The above scenario in which Na-HCO_3 pore water at a moderate level of total dissolved solids is produced requires the presence of appreciable dissolved oxygen in the water that penetrates through the soil and sandy subsoil to the finer-grained zone below. It is unlikely that this would occur. It is more reasonable to expect that much of the dissolved oxygen would be consumed in the soil zone by oxidation of organic matter. It should be noted, however, that little is known about the occurrence of dissolved oxygen in soil moisture in sandy subsoils beneath soils that support crops or grasses. The downward flux of dissolved oxygen below the root zone will depend on the vegetation conditions, on the rate and frequency of infiltration, on the nature and distribution of soil organic matter, and on the character of the soil bacterial environment. The bacterial system is important because bacteria act as catalysts in the oxidation process.

If most of the dissolved oxygen is consumed by oxidation of organic matter above the root zone, oxidation of pyrite by the remaining oxygen will cause release of only a minor amount of H^+. The addition of HCO_3^- to the pore water from calcite will be small and the increase in Na^+ by ion exchange will also be small. The pore water will be low in total dissolved solids (a few hundred milligrams per litre), slightly alkaline (pH from 7 to 8), and will have Na^+ and HCO_3^- as the dominant ions.

The above line of reasoning draws attention to the fact that a fine-grained, sodic, pyritic sediment placed below the root zone in cast overburden can be expected to produce minimal salinity in comparison to salinity production that would occur if this material is placed immediately below the veneer of top soil. As an oversimplification it could be stated that the salinity production capacity of these materials will not be mobilized if the material is isolated from the zone of great geochemical activity which occurs in the upper two or three metres of the landscape. It should be noted that because salts can be generated in materials that do not initially contain salt minerals, the standard tests that are used to identify saline or potentially saline soils are not useful as a measurement of the salinity production capactiy of these materials.

Since sand with low silt and clay content is not abundant in most areas where mining may occur, the question of how thick a sand layer beneath the soil is necessary is a general one. The deposits placed beneath the land layer will be less permeable. The veneer of soil on top of the sand layer will be relatively permeable as a result of the effects of cultivation, root channels, dessication, and freeze-thaw cycles. If infiltration frequently passes through the soil and sand, the water table will eventurally rise in the sand because of the lower permeability of material at the base of the sand.

In the climatic setting of western North Dakota, passage of rainfall or snowmelt through the sand will probably be infrequent if the sand is at least a few metres thick and if grass or crops that stimulate evapotranspiration are established. If irrigation were to be practiced, careful water management would be necessary to prevent excessive groundwater recharge. If the permeability contrast between the sandy subsoil sayer and the underlying deposit is appreciable, lateral flow in a saturated zone in the lower part of the sand will be the main mechanism of water flow from the sand if there is a sufficient slope in the water table. Construction of the cast overburden in a manner that will produce sufficient lateral groundwater runoff in the event that excessive infiltration through the root zone occurs would be a necessary objective in the mineland reclamation program. The groundwater zone developed at the base of the sand would be in a perched water-table condition during at least the first few years or decades of the 'wetting up' phase of adjustment of the cast over-burden to the hydrologic conditions. Eventually the finer-grained deposits below the more permeable deposits would become saturated.

As indicated above, the water that drains from the sand, either laterally or downward, will be low in dissolved solids. It will nevertheless cause mineral precipitates (salts of Na, Ca, CO_3 and and SO_4) to form in the soil and or on the surface at locations where the groundwater discharges. As the cast overburden below the sand wets up, lateral discharge from these finer-grained materials will also produce salinity in the discharge zones. It is evident that the morphology of the cast overburden should be designed so to minimize the area affected by these salts. These discharge areas will probably not be suitable for agricultural producation. Hydrogeologic studies in western North Dakota indicate that under natural conditions the percentage of the landscape occuppied by groundwater discharge zones is extremely small. This is not the case in some parts of the Great Plains Region. The difference can be mainly attributed to differences in the distribution of the geologic materials and the topography. Since these factors can be partly controlled in the cast overburden environment, we expect that careful design will lead to the occurrence of only small saline zones in discharge areas.

If the objective of reclamation is to develop a post-mining landscape that is agriculturally productive, some attention must be paid to providing potable water to farmers living on the reclaimed land. The majority of the farms in the areas in which there is a potential for strip mining have wells located in or above the main coal bed. In some of these areas there are aquifers with potable water below the zone which would be mined. Regional hydrogeological studies indicate that mining and land reclamation will in general have no significant effect on these aquifers.

In much of western North Dakota, however, the aquifers below the main coal contain water of poor quality.

It would be very desirable if, in areas of the reclaimed landscape where groundwater of acceptable quality cannot be obtained below the mined zone, groundwater were to be available from aquifers in the cast overburden. If zones of relatively clean sand are constructed at or near the base of the cast overburden, the water table will gradually rise in the cast overburden providing a zone of sufficient permeablility that would enable wells for farm water supply to be constructed. To promote replenishment of water in the aquifer, the surface topography of the cast overburden could be constructed so that surface water tends to accumulate in areas that would provide direct recharge to the aquifer. It would probably be desirable to avoid emplacement of clayey materials above the aquifer sand, since these materials may prevent adequate recharge. The limiting factor in this regard may be the availability of sufficient non-clayey material. It should be kept in mind, however, that aquifers for supply of farm water, with the exception of irrigation water, can be adequate even if they are relatively small.

Prior to actual construction of an aquifer in cast overburden, the most difficult questions to answer will be those of water quality. If most of the recharge to the aquifer occurs as a result of runoff of surface water to local topographic lows, and if the water infiltrates through clean sand in the root zone and through sand or at least non-clayey materials below the root zone before entering the aquifer, the water will very likely be of acceptable quality in terms of its major ionic constituents. In terms of these constituents, the water in the cast-overburden aquifer would differ from natural water mainly by its low content of SO_4^{2-}.

What is much less certain, however, would be the concentrations of trace metals that would develop in the aquifer water. Since little is known about the occurrence of and geochemical controls on trace metals in the natural groundwater in the region, there is no interpretive framework available upon which to base predictions. There is some possibility that the materials in the cast overburden, while under natural conditions, contain groundwater with acceptable concentrations of trace elements, will release higher concentrations of these metals to water in the cast overburden as the water encounters surface areas that were previously not well exposed to circulating water. Field studies of the chemistry of groundwater in cast overburden that are currently in progress at several sites in western North Dakota, should shed some light on the geochemistry of trace elements in these materials.

Summary of Conclusions

1. With existing methods of field investigation, the spatial distribution of the various types of geologic materials in the areas of actual or potential coal mining in western North Dakota are being successfully defined in detail. This process proceeds most efficiently when a conceptual framework based on interpretations of the original depositional environments of the sediments is used as a basis for the designs of drilling and sampling programs.
2. Studies of the groundwater conditions in areas of actual or potential mining and studies of soil moisture conditions elsewhere in the region indicate that nearly all of the water from rain and snow that penetrates the ground surface does not infiltrate below the root zone. This water is lost by evapotranspiration. Groundwater recharge is infrequent and generally occurs most significantly in local topographic depressions. The fact that water frequently penetrates into the soil and shallow subsoil but rarely passes through it is a key factor in the development of salinity in the soil and in the underlying groundwater zone.
3. Studies of the chemistry of groundwater in areas of actual or potential mining indicate that the salts that occur in the natural groundwater are derived almost entirely by geochemical processes that are active in the soil and in the subsoil zone above the bottom limit of the root zone. That is, the water acquires its salts in the upper few metres of the hydrologic system. This is the case even though the subsurface water flows much farther and resides much longer in the groundwater zone located well below this shallow zone of geochemical activity.

4. The key to the development of an agriculturally productive post-mining landscape will be to arrange the geologic materials that are excavated during mining into a landscape that will preclude the development of saline soil water in the upper two or three metres of the cast overburden. It appears that this will be possible to accomplish if fine-grained, sodic, pyrite-rich materials are excluded from this geochemically active zone. These materials, which are capable of generation of large quantities of SO_4^{2-} and indirectly of Na^+ in the pore water, are relatively inactive geochemically when they are located below the zone of frequent oxygenation and salt concentration by evapotranspiration.

5. In the construction of productive post-mining landscapes the two most valuable geologic materials in the cast overburden are relatively clean sand and glacial till that contains little to no sodium or pyrite. Most sites have not been glaciated so till is generally absent. According to the interpretive geologic framework that has been developed, the sands that occur in the Tertiary bedrock were deposited in channels in flood-plain environments. These sands should serve as good subsoil material. It is important in investigations of the geology of the zone above the main coal to identify and delineate these deposits. During excavation these sands should be isolated from the other deposits and used carefully in the construction of the post-mining landscape.

6. If sufficient quantities of channel sands are present above the main coal, it may be feasible to construct aquifers within the cast overburden. These aquifers, which need not be very large, could supply the non-irrigation needs of farms that will be re-established on the post-mining landscape. Local topography could be constructed in a manner to promote recharge to the aquifers. If the upper few metres of the post-mining landscape is constructed in a manner that will minimize the long-term production of salts, the water that will gradually accumulate in the artificial aquifers will have lower total dissolved solids and much lower Na^+ and SO_4^{2-} concentrations than most natural groundwater that occurs at present in the main

coal and in aquifers above it. The main uncertainty with regard to the chemistry of groundwater in the artificial aquifers will be the concentrations of trace elements. At this time little can be said about the possibilities for occurrence of excessive trace-element concentrations.

7. The simple approach to land reclamation whereby top soil is placed over an unselected mixture of geologic materials excavated from above the main coal should be unacceptable as a land management framework. Careful selection and enplacement of geologic materials below the top soil has potential to yield great benefits over long periods of time. Whether or not the benefits will justify the additional expense is a topic beyond the scope of this paper, which has only presented a preliminary view of the development of some aspects of a conceptual approach to mineland reclamation.

8. The concepts for mineland reclamation presented herein have been based primarily on interpretive frameworks developed during regional scale studies of the geology, hydrology, and geochemistry of groundwater in selected areas of western North Dakota. We wish to emphasize that before embarking on a program of landscape construction that embodies the main ingredients of any of the concepts described here, it is essential that detailed studies on a very local scale be undertaken in areas of natural terrain and in reclaimed overburden. In western North Dakota it is appropriate that some of the research emphasis that is now placed on regional studies directed at large-scale impacts be shifted to more local, intensive studies that have a truly interdisciplinary approach involving hydrologists geologists, geochemists, chemists, agronomists, soil physicists, and plant scientists.

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PAPER

-5-

Paper No. 5

Author(s): A.E.A. Schumacher, R. Hermesh, and A.L. Bedwany

Title of Paper: "Coal Mine Spoils and Their Revegetation Patterns in Central Alberta"

ABSTRACT

The reclamation of land disturbed through surface mining is made mandatory in Alberta through the provision of the Land Conservation and Reclamation Act (1974). The objectives of land Reclamation are outlined in the Coal Development Policy for Alberta as follows:

> "The primary objective in land reclamation is to ensure that the mined or disturbed land will be returned to a state which will support plant and animal life or be otherwise productive or useful to man at least to the degree it was before it was disturbed. In many instances the land can be reclaimed to make it more productive, useful, or desirable than it was in its original state; every effort will be made towards this end."*

The term productive is ill-defined and open to different value interpretations. It implies, however, the re-establishment of a healthy and viable vegetative cover on the surface.

There has, in the past, been considerable public debate over the long-term implications in the maintenance of productivity on reclaimed land. There have been those who have predicted permanent loss of productivity, and those who have foreseen little if any change in productivity and even improvements in some cases. In fact, there is little hard evidence supporting the arguments of either camp, and many of the predictions are extrapolations based on current theories of the chemical, physical and biological behaviour of soils. There is, however, irrefutable evidence that short-term growth is dramatically improved by the selection and placement of more favourable growth media at the surface. This does not necessarily include the use of topsoil.

* Department of Energy & Natural Resources, Government of Alberta. June 15, 1976.

In view of the situation just described and of the recent nature of much of the research on strip mine reclamation, especiall in Alberta, it was essential to take a close look at some of the older spoils in the province. In this connection a historical study of the dynamic processes occurring in spoils was undertaken by Calgary Power through their consultants Montreal Engineering.

The study involved an examination of the vegetation and spo on five mine locations in the central Parkland of Alberta. These five locations represented different spoil types, and methods of mining. Within these spoil locations 44 sites were selected which represented spoil and vegetation conditions at different ages and topographic positions.

Some of the most important conclusions were:

1. The vegetative productivity of mine spoils in Central Alberta can be restored even given only a minimum of reclamation inputs.
2. The composition of the surface material is the most important factor affecting the reclamation of spoils. This factor can be manipulated by mining techniques.
3. The addition of topsoil to the spoil surface is not an absolute requirement to successful reclamation. However, topsoiling probably significantly reduces the time period required for reclamation.
4. Under conditions of natural plant invasion there are distinct successional stages leading to the eventual production of plant communities resembling those occurring in the original aspen parkland. However, these stages may be slowed or halted by adverse spoil conditions or overgrazing.

Coal Mine Spoils
And Their Revegetation Patterns
In Central Alberta

Alex E.A. Schumacher
Reinhard Hermesh
Antoine L. Bedwany

INTRODUCTION

There has been a relatively brief period in which methodical and scientific studies have been pursued, dealing specifically with the reclamation of mine spoils (Montreal Engineering 1976a, Packer 1974, Varies 1976, Wali 1975). There is thus a general lack of experience and knowledge of the changes occurring in spoils over time and of the changes that occur in the associated vegetation. This study, commissioned by Calgary Power Ltd., was designed to compensate for this lack of experience in the Aspen Parkland Region of Alberta by going back to abandoned spoils of various ages to investigate the manner in which they have changed with time. The relationship between the internal chemical and physical changes and the variation of surface vegetation was considered to be a particularly interesting aspect of the study because of the insights which it was hoped this would give into the sequences to be followed in establishing permanently self-sustaining plant communities.

The most important elements in attempting to achieve these objectives were considered to be: (1) the survey of the morphological, physical and chemical properties of the spoils and (2) the correlation of these spoil characteristics with the spoil age and with the species composition, the cover and the productivity of the associated vegetation.

The sites discussed in this report were selected on the basis of their geographic locations, the age of the spoils, the types of vegetation present and method of mining. They were all situated within the Aspen Parkland belt of central Alberta on spoils from the Dodds, Black Nugget, Ryalta, Burnstad, Pleasure Island (Camrose Collieries) and Forestburg mines, Figure 1.

The spoils evaluated during this study have been treated essentially as soils. The older spoils display many symptoms of incipient soil formation such as the downward mobilization of salts and their accumulation deeper in the profile, and also the accumulation montreal engineering company, limited

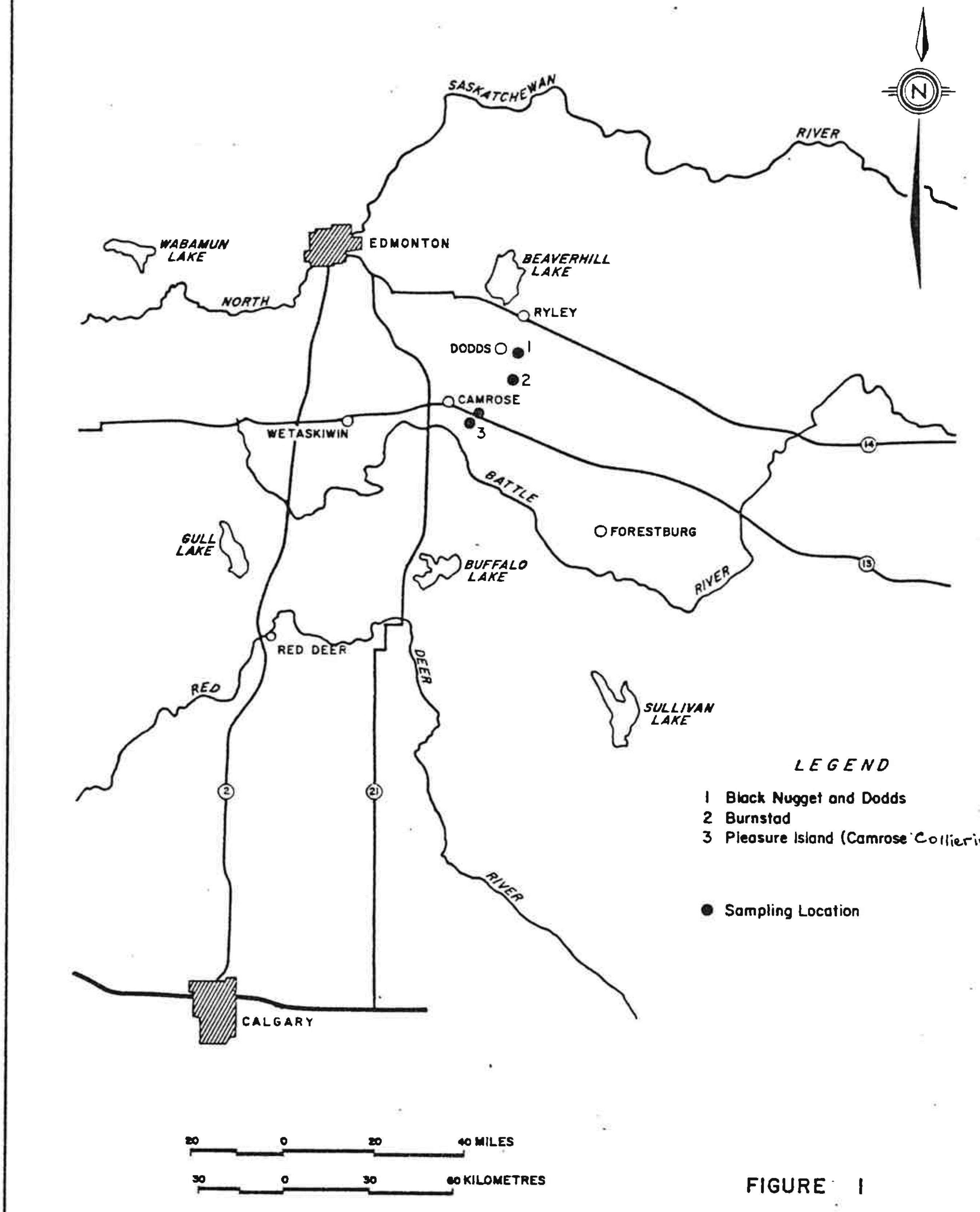

FIGURE 1

LOCATION MAP OF STUDY ARE

of organic matter in the surface layers. In other senses as well, the spoils resemble soils; they have significant cation exchange capacity, they are mostly biologically active and they provide mechanical support for whatever is growing in them. Finally, it is true to say that given time these spoils will in any case develop into soils with the same or similar characteristics to any of those found in adjacent areas.

II MATERIALS AND METHODS

The study areas were visited, and interviews held with the individuals familiar with the mining history and procedures. On the basis of this information five mine locations were selected representing different spoil types and methods of mining. Within these spoil locations 44 sites were selected which represented spoils and vegetation conditions on spoils of different age groupings and topographical positions.

The test pits were excavated to a depth of 120-180 cm (4-6 ft) with a tractor-mounted backhoe. Detailed notes were taken on the morphological features of the spoils including texture, consistency, compaction and permeability as well as root penetration and distribution with depth. The descriptions were based on the standards of "The System of Soil Classification for Canada" while colours were described according to the "Revised Standard Soil Colour Chart System" (Oyama and Takehara 1967). The vegetative sampling consisted of three phases designed to obtain an in-depth appreciation of the vegetative community which had developed on each site. The three phases were: (1) an estimate of species composition and cover, (2) an estimate, or where possible a measurement, of site productivity and (3) a photographic record. The nomenclature was based on Moss (1959) in all cases.

Soil analyses were conducted by Chemex Laboratories Ltd. of Calgary using standard soil analytical techniques. The parameters identified were, particle size distribution, cation exchange capacity, pH, electrical conductivity, soluble cations (Na, Ca and Mg), plant nutrients (available N, P and exchangeable K) and carbonates.

The sodium absorption ratio was calculated from the results of the soluble cation analyses.

III RESULTS

1. Particle Size Distribution (Texture)

The particle size distribution of the spoils was mainly related to the material(s) from which they were derived. The sampled spoils were mixtures of till, shale, sand/siltstone, coal remains and portions of the original soils. Some samples consisted almost entirely of one or two of these constituents but the majority consisted of more. The reported results, thus, represented the average textures of the "homogenized samples" after mixing and sieving in the laboratory.

The greatest proportion of the sites had sandy loam textures reflecting the predominantly sandy nature of the underlying Edmonton formation. Finer textures probably represented different admixtures of shale with the sandstones.

Certain anomalies in the distribution of textural classes can be associated with the mining techniques that were used. At the Burnstad, Pleasure Island, Dodds - Black Nugget and Ryalta sites heavy earth moving equipment such as scrapers and bulldozers removed the over burden layer by layer and redeposited it in the reverse order to that in which it was originally encountered. The continual passage of the machinery tended to compact each layer as it was deposited.

At the Burnstad and Pleasure Island sites the material lying directly over the coal and in the partings was a saline bentonitic shale. This was the last to be removed and was deposited over most of the surface. It was reflected in the high incidence of moderately fine textures (38% finer than sandy clay loam) on the surface and the lack of plant growth. At the Dodds and Black Nugget sites a thin sand/siltstone layer lying immediately over the bentonitic layer appears to have been mixed with it during the mining, thereby ameliorating it.

The dragline mining method used at Forestburg resulted in a very different distribution of materials from that observed where scrapers were used. The majority of samples (81%) were sandy loams while the remainder (19%) were loams. The surface materials are also dominantly (71%) sandy loams while the remainder (29%) are loams. It is thus evident that the dragline method resulted in a more thorough mixing of the spoils. However, the till and bedrock at this site likely also consisted initially of coarser materials than occurred elsewhere. This is borne out by the observation that the shales at Forestburg have a sandy clay loam texture, while those at Burnstad have a clay loam texture.

2. Reaction (pH)

The spoils were generally mildly alkaline, reflecting the calcareous nature of the bedrock formations and of the tills formed from them. Strongly alkaline conditions were recorded at the Dodds and Black Nugget sites and moderately alkaline conditions in the sub-surface materials of all other sites. Only at Burnstad, however, were moderately alkaline conditions encountered at the surface.

No strongly alkaline conditions were encountered in the surface spoils and with the exception of the Burnstad site, most would provide a suitable plant root environment from the pH standpoint. The few strongly acid samples, all of which were from the Burnstad site, probably represent leached Ae horizons of the Angus Ridge loam which originally occupied the surface.

3 Salinity

The spoils conditions ranging from non-saline to moderately saline were encountered but weakly saline conditions were predominant (49% of samples). A large proportion (44%) of spoils were non-saline, only a few (8%) moderately saline and none strongly saline.

The surface samples are mostly non-saline but a significant proportion (36%) displayed weakly saline characteristics.

Some of the salinity data is presented in graphic form in Figures 2 and 3. Inspection of this material makes it possible to identify some trends in the relationship between salinity, time, composition and depth of spoils.

1. In every case salinity increased with depth and also tended to be highest in those layers containing the largest proportion of shale.
2. Many of the older, mainly-till spoils were non-saline throughout the entire depth of the potential rooting zone of 120 cm (4 ft).
3. Younger spoils show a more even distribution of salts within this zone.
4. The shale-rich spoils show a much slower rate of leaching than the coarser till materials (see graphs of Burnstad and Dodds sites).

This evidence of salt movement suggests that under the prevailing climatic conditions salts will tend to move down the profile, especially in coarser, better drained situations. Exceptionally high levels of soluble salts were, however, encountered in the surface layers of some sites. This was attributed to the combined effects of the fine textures and a very high degree of compaction resulting in low permeability. Upward capillary action had thus tended to predominate in place of downward leaching and the situation was worsened by

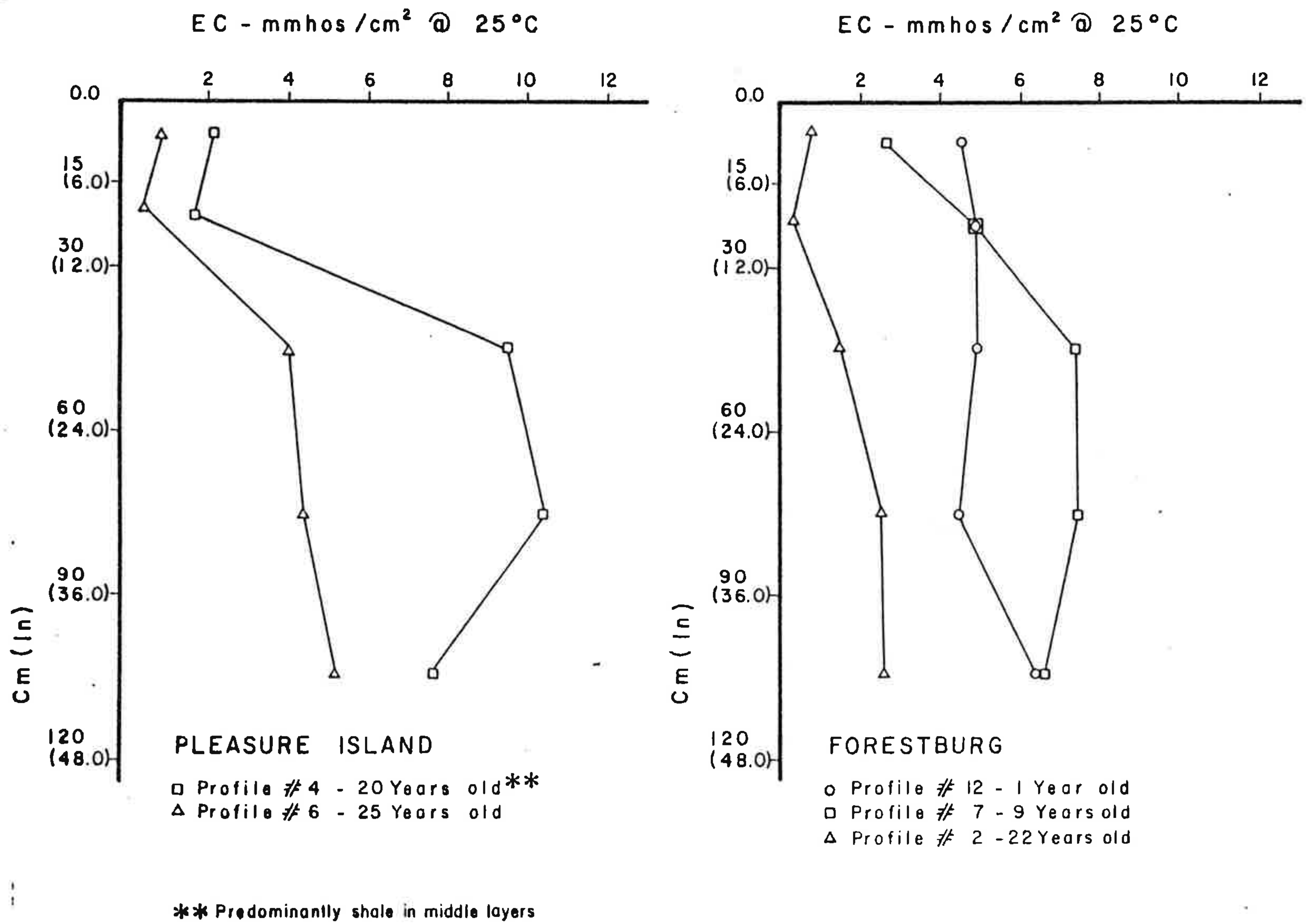

FIGURE 2

SALINITY PROFILES OF
SELECTED SPOILS SAMPLES OF VARIOUS AGES

montreal engineering company, limited

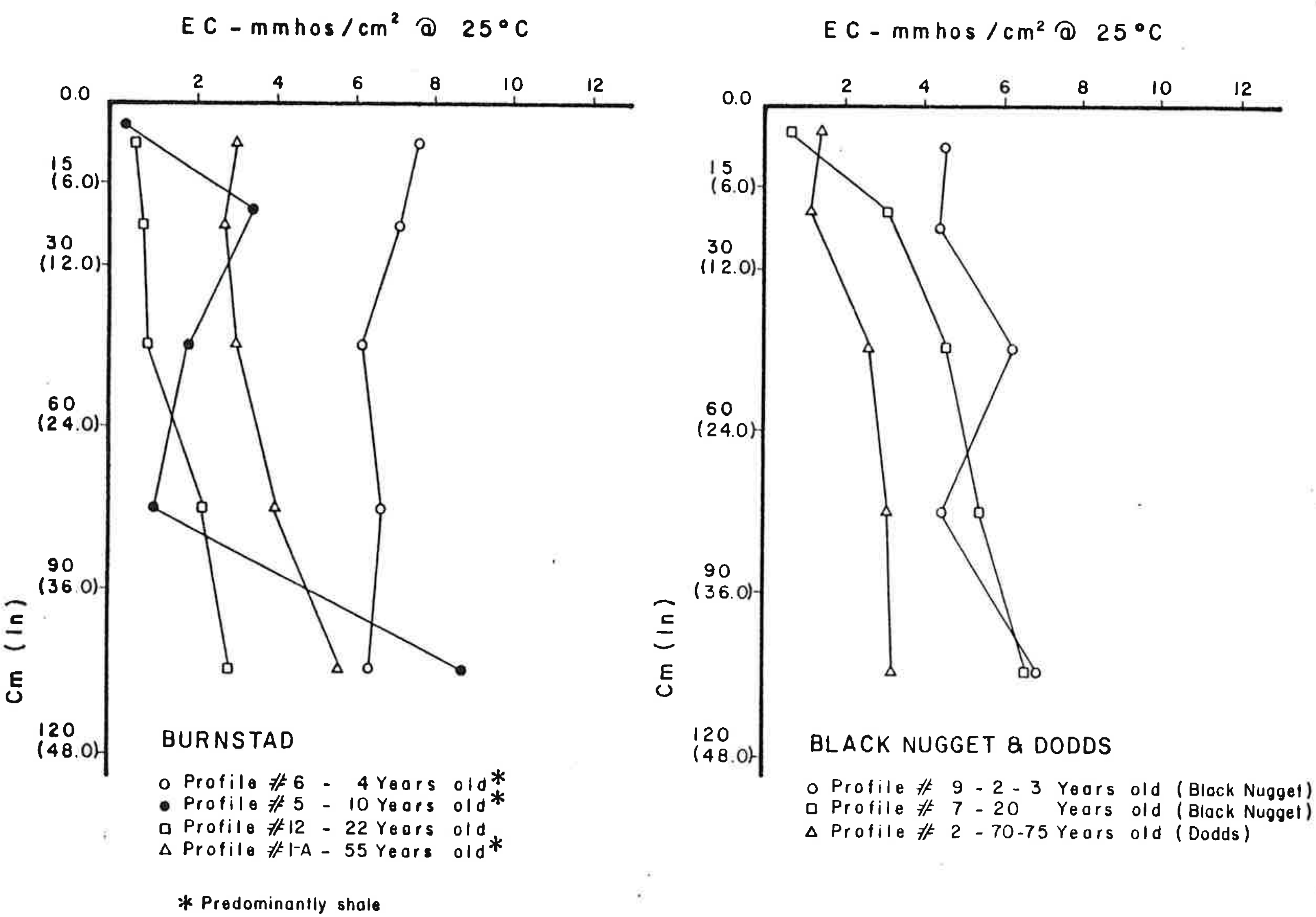

FIGURE 3

SALINITY PROFILES OF
SELECTED SPOILS SAMPLES OF VARIOUS AGES

a lack of surface vegetation. At the Forestburg site, the salinity was attributed to the fact that it was located in a sparsely vegetated depression. Run-off and sub-surface flows accumulated here tending to concentrate salts as the excess water is evaporated off.

4. Sodium

The most seriously sodium-affected spoils were at the Burnstad, Black Nugget-Dodds and Pleasure Island sites. However, only at Burnstad did these conditions prevail on the surface. Slightly less serious, but still potentially toxic conditions (SAR >18) were encountered in a few samples from every location but the Ryalta mine. Low and medium sodium levels (SAR <18) were encountered sporadically throughout all sites. These levels are generally not detrimental to plant growth, but towards the upper end of the range the sodium might reduce the amount of water available to plants under droughty conditions.

The relationship between the SAR and the total soluble salts was considered for each of the sites and for three age groupings of the spoils. These data reflect all the error introduced by the selection of the sites because of the special characteristics which required studying. They, however, gave an indication of some of the dynamics that occur in the spoils and involve those major parameters associated with salinity. There was a highly significant correlation between these two parameters in every site suggesting at very least the common origins of the salts and the sodium. With the exception of the Forestburg sites ($r^2 = 0.77$), the degree of variance in the SAR values was not more than 37%, explicable by the variance in the total salinity. This may be explained by the fact that the levels of both are more a function of texture and of the presence of shales. At the Forestburg sites, however, the textures are all loam or sandy loam which would leach rapidly. The salts and the sodium are thus more mobile in the profile and appear to be more closely related to one another.

5 Carbonates

Most of the component materials of the spoils contain alkaline earth carbonates derived mainly from the till, and the shale and from the horizons of secondary lime accumulation (Ca or Csaca) of the original solonetzic and chernozemic soils.

There was no identifiable correlation between the $CaCO_3$ content and the age and depth of the spoils. This suggests that the carbonates were much less mobile than the other soluble salts and that it would take a very long time (possibly centuries) for the formation of a layer of lime accumulation similar to that found in the original soils.

6 Cation Exchange Capacity (CEC)

47 percent of all samples ranged in CEC from 50 to 96 Meq/100 g. These relatively high CECs coincide with finer textures related mainly to higher amounts of shale, and also possibly to a higher content of illitic and montmorillonitic clays in the colloidal fraction of these samples.

The CEC data suggest that the spoils of all five study areas contain sufficient amounts of colloids to adsorb and supply the basic nutritional elements to most plant species.

7 Fertility

The highest concentrations of both available N and P in all the samples are much lower than the suggested deficiency levels of these elements for both cereal and legume crops in central Alberta. The reported concentrations of exchangeable K are sufficient, however, to meet the minimum requirements of such crops.

8 Morphological Characteristics

Some of the older vegetated spoils exhibit a noticeable increase in organic matter content, accompanied by a relatively darker colour and a somewhat granular structure in their surface layers. It was often difficult, however, to precisely differentiate between organic matter build-up as a result of root growth and biological activity, and that which resulted from the disintegration of the fine coal residue.

There was no visible evidence of the formation of genetic horizons within the spoils apart from slight changes in the granulation and colour of the surface of some profiles which might be identified as Ahj horizons. The structure was that of a compacted mass with no development of identifiable structural units (peds), as is the case in normal soils. A thin but firm crust was observed on the surface of the spoils which lacked or had a sparse vegetative cover. This resulted from the dispersion of the spoil particles under the direct impact of rainfall, and from repeated wetting and drying.

Compaction was greatest in the spoils which contained higher amounts of shale and in the areas where heavy tractors and scrapers were used in mining. In these areas, the effect of high compaction by this type of machinery combined with relatively fine textures was reflected in a shallower depth of penetration of the finer roots.

It was noted, however, that the presence of a visible quantity of coal residue in these spoils was accompanied by a deeper root system. Furthermore, the roots appeared healthier and well rounded. This may be attributed to the improvement in spoil/water/air relationships associated with the creation of larger pores and considerable decrease in the effect of compaction. Plentiful fine and medium roots were also observed growing in almost "pure" coarse fragmental coal layers.

9 Natural Revegetation

Within the mine areas studied, a characteristic sequence of vegetative plant succession was observed consisting of a number of discrete and identifiable vegetative stages. (Table I). Each stage was associated with certain characteristic species assemblages and appeared to occur within an approximate time span.

TABLE I

Stage of Revegetation

Vegetative Stage	Time Frame
Forb stage	1 - 4 years
Early grassland-weed stage	5 - 20 years
Early grassland stage	20 - 30 years
Grassland stage	30 - 50 years
Early aspen parkland stage	50+ years

Those naturally reclaimed areas which had suffered cattle grazing provided the best examples of each of these vegetative stages but it is likely that most mine sites pass through a similar progression. However, the development can be altered or even halted at any stage by adverse factors, the most prevalent of which are extremely adverse soil conditions and extensive grazing and overgrazing by cattle.

10. Description of Vegetative Stages

During the first stage most raw spoils were invaded by a variety of forbs, especially sweet clover. Few other species were present, apart from occasional individuals of brome or other grasses and foxtail barley in saline areas.

After a period of growth lasting approximately three to four years the sweet clover died back to be generally replaced by foxtail barley and numerous weedy species. With the collapse of the sweet clover the site productivity fell to very low levels and a stage began in which the site slowly developed into a grassland. The salt-tolerant foxtail barley was replaced by brome grass which eventually became the predominant grass species. The proportion of grasses slowly increased with time at the expense of the weeds. This initial grassland stage appeared to last for 15-20 years during which time the productivity of the site also slowly increased (Table 2).

About 20 years after mining, the first aspen trees, or willows in more moist sites, began to invade. The initial pioneers slowly spread by vegetative propagation to become the nuclei of the aspen groves found later. By about 30 years after mining, fairly large clumps of aspen had formed and the site took the outward appearance of the aspen parkland which originally dominated the area (Table 3).

The species composition of both the aspen groves and the grasslands were initially quite different from the original stands. The predominantly brome grassland may however be seen to be invaded and replaced by blue grasses and wheat grass which at the Black Nugget was being replaced by rough fescue. The original clumps appeared to be very stunted but some of the newer stands displayed better growth probably in response to improvements in the root zone. Undergrowth of the aspen at first was consisting mostly of roses, but more species seem to have invaded with the development of a richer assemblage. The most striking changes occurring were:

1. the increase in the grass cover with time along with a concomitant decrease in herbs,
2. the increase in the number of species present from 14 after 2 years to 50 after 31 years,

TABLE 2

Number of Species Present Related to Spoil Age

Age of Spoil	Numbers of Species Present				Total Species Present	Productivity	
	Grass	Herbs	Shrubs	Trees			
yrs						g/m^2	lbs/a
2	4	10	-	-	14	438.2	3,910
19	6	11	2	1	20	302.5	2,907
31	7	35	6	2	50	445.5	3,966

TABLE 3

Cover of Grassland Areas on Spoil Piles*

Age of Spoil	Percent Cover		
	Grass	Herbs	Bare Ground
yrs	%	%	%
2	5.3	79.1	15.6
19	39.4	49.4	11.2
31	67.4	36.9	-

* Total cover is over 100% due to formation of strata.

3. the high productivity related to the initial growth of sweet clover, its subsequent decline during the early grassland-weed stage and a build-up as the grassland stage progressed.

The vegetation of the regenerating aspen groves at the Black Nugget Park, a 30 year old site, were compared with that of ungrazed groves found in the vicinity. Of the 26 species re-established in the groves, 19 were common with at least one of the comparative sites. The remainder were mostly foreign to aspen grove vegetation (e.g. sweet clover, sage, thistles) and were expected to die out with time.

A total cover within groves declined with increasing dryness of the sites and as would be expected the lowest total cover occurred on the spoil sites. The percentage cover of trees, small and medium shrubs, herbs and grasses was comparable with at least one other site. Only the percentage of tall shrubs was lower on the spoil site than on any natural site surveyed.

IV CONCLUSIONS

The composition of the surface 1-2 m (3-6 ft) is probably the most important feature of the spoils with respect to the successful introduction of plants. The initial composition of this layer is both a reflection of the strata present and the mining method used. The layer by layer removal and re-deposition of spoils by heavy equipment such as bulldozers and tractor-drawn scrapers or even by horse-drawn scrapers has resulted in the formation of a poor growth medium in many of the older sites, with the exception of Black Nugget. The strata were replaced in the reverse order to that in which they originally occurred and the most problematic materials such as the saline shale layers left on the surface. The continuous passage of machines or even animals has also caused severe compaction and deterioration of the physical characteristics of the potential rooting zones. In contrast, a dragline cutting vertically through the strata tends to mix the overburden materials more thoroughly and results in more heterogeneous spoils with less compaction.

Free surface drainage and lack of compaction allows the rapid removal of potentially harmful salts by leaching, and easy penetration by plant roots. This situation can only be maintained provided there are loams or coarser materials throughout the potential root zone and preferably deeper. Materials as coarse as loamy sand and sand should, however, be avoided because of their low moisture holding capacity and infertility. The introduction of coal dust and fine particles into potentially problematic materials such as shales appears to greatly improve their physical characteristics and also the quality of the vegetation cover. Roots of plants growing where coal fragments are abundant are more plentiful and appear to be healthy and well-rounded. These observations bear out conclusions made by Fairbourn (1974) on the effect of using small coal fragments as a mulch.

Salinity is one of the major limiting factors to plant establishment, especially when combined with fine textured materials or occurring in poorly drained situations. Variations of salt levels down the profile are associated with textural variations. It was observed that salinity tends to be highest in layers having the highest proportion of shales. In addition, the levels of salts in high shale material decreases only slowly with time. The slow rate of leaching is related to the relative impermeability of the shales, especially when compacted and dispersed because of high sodium levels. Leaching, demonstrated by a general increase of salinity with depth, was observed to occur in most profiles inspected. In some of the older spoils composed predominantly of till materials the entire rooting zone (1.2 m or 4 ft) was non-saline. Conversely the younger, more saline profiles tend to have salts more evenly distributed throughout the profile but with high concentrations corresponding to the shaley layers.

There is a close correlation between the total soluble salts and the SAR. Both parameters generally increase with depth, especially in the older spoils, and both are higher in spoils with higher proportions of shales. The two factors are not, however, always directly attributable to one another since many soluble salts are relatively mobile. Much of the sodium is adsorbed onto the exchange complex.

There is good evidence from such sites as Dodds and Forestburg, that, provided the materials deposited at the surface are of suitable texture and have not been overly compacted, they will in time develop into productive plant growth media. It is concluded from this that the addition of topsoil is not an absolute necessity and could be foregone in some instances. This is especially so where the original topsoil is impoverished and where there are no inherent problems associated with the underlying till or bedrock. The major benefit of adding topsoil appears to be that derived from the presence of organic matter, the levels of which would otherise take many years of careful husbandry to develop to an acceptable level. The organic matter would significantly increase the cation exchange capacity and probably improve the availability of nitrogen and phosphorus both of which were markedly deficient in the spoils surveyed.

The spoils have a similar cation exchange capacity to most of the normal soils of the study areas and, therefore, the potential to adsorb and supply nutritional elements to plants.

A number of distinct successional stages were recognized in the vegetation recolonizing the spoil sites. The initial stages are simple with very few species managing to establish themselves. Predominant amongst the early colonizers is sweet clover which dies out after a few years, leaving a much less dense vegetative stand. As the succession proceeds, the developing plant community becomes more diverse. In the final stage the vegetation likely resembles the climax of the region. This was not observed to have been completely achieved, although in Dodds an early aspen parkland vegetative stage has been reached. This vegetative succession can be halted or considerably slowed at any stage as a result of adverse spoil conditions, such as compaction or the presence of saline (or alkali or saline/alkali) conditions. Disturbances such as overgrazing also cause severe limitation to the development of a plant cover.

In the benign spoils (those without significant levels of plant toxins) the productivity appears to be mainly related to the age of the spoils and the stage of succession of the vegetation. This is probably due to the gradual build up of the organic system in the spoil and emphasizes the importance of maximizing the level of organic matter as rapidly as possible on land to be used for sustained agricultural production. In these same benign spoils there appears to be evidence that their productivity will, with time, equal or exceed that of the native prairie vegetation, even without any reclamation inputs.

In the later stages of succession, spoils make good wildlife habitat, especially where levelling has been kept to a minimum and where a tree cover has been re-established. Numerous species of birds and mammals are attracted by the varied topography and micro-climates that thrive in the spoil habitat. Furthermore, ponds such as those at Black Nugget provide adequate habitat for beaver, muskrat, introduced fish and waterfowl. These in turn attract recreational use of the areas, thus providing an important outlet for the adjoining urban areas.

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PAPER

-6-

SURFACE RECLAMATION SITUATIONS AND PRACTICES ON COAL EXPLORATION AND SURFACE MINE SITES AT SPARWOOD, B.C.

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Kaiser Resources Ltd.

ABSTRACT:

Kaiser Resources Ltd. ownes and operates a 5 million ton per year open pit and hydraulic coal mine near Sparwood in Southeastern British Columbia.

Since 1969, Kaiser has maintained a field scale reclamation program dedicated to reclamation of disturbances associated with past and present mining and exploration activities. Since that time, over 1400 acres have been treated using modified forestry and agricultural techniques with encouraging results.

KEYWORDS:

Coal, Reclamation, Exploration, Mining

INTRODUCTION

In 1968 Kaiser Resources Ltd. announced its intention to develop extensive coal deposits in the southeastern corner of British Columbia. The resulting public reaction against the possible damage of these wilderness areas was responsible for the formulation of provincial regulations for reclamation, specifically Section 8 of the Coal Mines Regulation Act and Section 11 of the Mines Regulation Act. At first this legislation applied, in the case of coal, only to open pit disturbances but was later ammended to include distrubances by exploration and underground mines.

No firm regulations have been established as to what constitutes a satisfactory reclamation. This is because of the wide variations of climate and topography within the province. Each operator has to determine the optimum results possible on a site specific basis.

In the summer of 1969 a Reclamation Department was established by Kaiser Resources Ltd. to determine the feasibility of reclamation and investigate the equipment, vegetative material and procedures necessary for a full scale reclamation program. In the spring of 1970 the Reclamation Department became fully operational with the hiring of two full time personnel charged with the development of a viable revegetation program for the whole property. Presently, the Reclamation Section of the Environmental Services Department has a permanent staff of 7 and a seasonal staff of up to 70.

The Kaiser Resources Ltd. property is located in the southeast corner of British Columbia. The title to a select two thirds of some 110,000 acres of coal bearing land previously held by Crows Nest Industries was acquired by Kaiser Resources Ltd. in February 1969.

The acreage acquired by Kaiser consists of two separate tracts of land, the larger being in the Crows Nest Coal Field and the second is a portion of the Elk River Coal Field.

The Crows Nest Field covers some 30 miles in length and is about 12 miles in width near the centre of the basin. The Michel mining area lies near the north end of this field and Fernie lies west of the centre. The Elk River Coal Field is about 8 miles north of Michel.

The Crows Nest Coal Field contains about 12 mineable seams that outcrop within a 2,500 foot stratigraphic sequence primarily along the western slopes of the Rocky Mountains. Similarily the Elk River Coal Field contains approximately 7 mineable seams that outcrop within a 1,500 foot sequence of coal bearing measures. The coal seams range in thickness from 5 to 50 feet and vary in elevation from 3,500 to 7,000 feet within the Elk River Coal Field.

The overburden on both coal fields is composed mainly of sandstone and carbonaceous shale with some conglomerate and calcareous shales. The pH of this material ranges from 4.2 to 7.8. The coal itself is a low volatile bituminous type with a low sulpher content of 0.3 to 0.4%.

The vegetation of this area is comprised of three different Biogeoclimatic Zones.-

a) The Interior Douglas fir zone from the valley bottom to 5,000 feet
b) The Engelmann spruce - Alpine fir zone at elevations from 4,500 to 7,000 feet
c) and the Alpine zone at elevations above 6,500 feet.

Steep topography and generally rugged terrain have broken these Biogeoclimatic zones into generally localized areas which blend one to the other. Also fires and past industrial activities have left a variety of successional stages throughout. Southern aspects tend to be composed of grasslands and shrubs whereas the more northerly slopes tend toward a conifer overstory.

MINING AND EXPLORATION METHODS

MINING

Presently, approximately 80% of Kaiser's coal production is derived from surface mining and 20% from underground methods, predominantly hydraulic. Although there is some surface disturbance which requires reclamation associated with underground mining, the majority of land disturbance is attributed to surface mining and exploration. These areas will be the basis of discussion in this report.

Kaiser's present approach to surface mining is a shovel and truck method. First the overburden is drilled and blasted and then it is excavated by large shovels, loaded into 200 ton trucks and hauled to dump sites. At the dump, the spoil material is disposed of in benches or terraces, each terrace wrapping around the slope below the preceeding one. Where feasible, spoil is backfilled into dormant areas or natural depressions.

As the overburden is removed in roughly 60 foot benches, the coal is exposed. This is then ripped and pushed up for front end loaders which load 100 ton trucks that haul coal from the pits to be processed.

EXPLORATION

Until 1974, Kaiser's coal exploration techniques closely resembled those used by most mining concerns. The general approach was extensive access road construction followed by seam tracing, trenching and test pit and adit sampling. This approach is no longer used at Kaiser.

Since 1974, the exploration approach has changed to one of access construction followed by drilling and more intensive geological mapping. Seam tracing and trenching techniques are no longer used. Adits are still driven but these are carefully located to avoid sedimentation of watercourses. Also adit waste, previously dumped at the most convenient place, is now salvaged for sale or is dumped into natural depressions and resloped to allow revegetation. All access roads and secondary drillsites roads are plotted on sensitivity maps and altered to minimize environmental damage. The are then flagged and inspected prior to construction. All roads that encounter merchantible timber are pre-logged before final road building thus salvaging the timber resource and eliminating the fire hazard of roadside slash.

Due to a great variety of climatic and edaphic conditions encountered over this large area, reclamation problems encountered vary in intensity and kind.

The valley bottom and lower slope areas pose much less problems than the middle and high elevation sites which tend to be much steeper and contain shallower, more sensitive soils and more extreme growing conditions.

One notable exception to this general trend is the problem of the erodability of glacial silts and sands found only at elevations below 4,500 feet. However, there still exists a general trend of increased difficulty of revegetation as the elevation increases.

Some of the major problems can be discussed in terms of soil, slope and aspect and species.

RECLAMATION PROBLEMS

SOIL PROBLEMS

After industrial disturbance, soils undergo dramatic change in chemical status, color, and structure, all of which frustrate revegetation efforts.

Chemical change is a general raising of pH up to 8.5 accompanied by a lower nutrient level, especially expressed in available nitrogen. These changes of course bring the pH range beyond the desirable range for tree species and some other native plants.

One other change caused by disturbance is a color change. The incorporation of dark marine shales and coal into the disturbed soil tends to make it much darker than the native soils. This trait decreases the albedo and hence increases heat absorption causing moisture levels, in a soil that already normally lacks moisture, to decrease. In an environment where available moisture in the growing season is so critical, color change can be a significant factor limiting revegetation of desirable species.

Finally, and certainly not the least important change in soil following disturbance is structure. In general terms, large disturbed sites such as overburden dumps or roads are characterized by a reduction in both organic matter and fine particles mainly due to burying and erosion. This reduces moisture retention and decreases cation exchange capacity of the growing medium. However, there are some advantages to an exposed soil that is coarse. This soil is more well drained and its potential for erosion is significantly lower than an exposed soil with high fines content. It is also important to note that gravitational sorting takes place in dump construction, with larger particles forming a crude filter at the toe of the dump. The friable nature of the exposed shales also allows soil building to proceed at an accelerated rate, especially when revegetation occurs concurrently.

SLOPE AND ASPECT PROBLEMS

Most disturbed areas usually end up, in general terms, somewhat steeper than "in situ" soils. These steep slopes present problems for regeneration because of surface creep, erosion, and other related items.

Dumping procedures and other practices which disturb large areas of land in mountainous terrain generally tend to make slopes more uniform, that is with less microsites and less variations in aspect. Also, draingage patterns tend to be diminished by filling of gulleys and low areas. The significance of these phenomena is that it makes revegetation more difficult especially if the final aspects left after disturbance are south or southwest facing. Mainly because of temperature and related moisture stress, these aspects have been found to be more difficult to reclaim.

SPECIES

The new and markedly different edaphic and induce climatic conditions of the dump slopes have resulted in a new environment for life. Unfortunately, some of the new conditions no longer suit the requirements of some of the previous users. For example, because of the increased pH and lowered organic matter content, most native tree species do not fare well. Paper birch and Black cottonwood are two notable exceptions. As far as native shrubs are concerned this is an area where great voids exist in the information available on requirement for growth and for seed stratification and propagation methods. Much research and experimentation is required in this area.

The importance of using native grasses and legumes has been emphasized and debated by may authors in range and reclamation research. Although Kaiser has and continues to use agronomic species of both grasses and legumes, recognition is given to the theory that this approach may not be the most suitable in the long run. Presently, both native grasses and legumes collocted over the past two years are being tested for viability in germination and growth tests. The use of native species will receive greater emphasis in reclamation work in the years to come, especially at higher elevations.

RECLAMATION METHODS

MINING

The most important phase of any reclamation programme must be site preparation. The primary objective of this is to re-establish watershed values on the disturbed sites and at the same time provide favorable conditions for the establishment of vegetation. At Kaiser Resources Ltd. the final disposition of spoil for reclamation is included in the overall mine plan. Because of the natural topography most spoil material is formed into large dumps with long steep slopes. Where this material is mainly fine spoil, a continual creep of the fine surface material prevents vegetation from becoming established. Earlier experiments indicated thet the maximum angle for successful revegetation on fine material is 28^{o}. In Kaiser's programme 26^{o} was the slope angle aimed at since it not only resulted in better seedling establishment but facilitated the subsequent operations of seeding, harrowing, and fertilizing. The angle of 26^{o} is used as a general rule where the reclamation plan is to contour the spoil dumps into the configuration of the similar surrounding landscapes. On the dumps formed by the operating mine this procedure is not feasible due to their slope lengths and massive size. An operating practice of forming dump terraces in a "wrap around" fashion as the mine is lowered greatly facilitates the reclamation plans. The incorporation of dump roads as terraces when resloping will reduce surface erosion and retain moisture for establishing vegetation. At first areas were resloped using 26^{o} as a maximum slope angle. However, as the work progressed it was felt that this particular spoil material could be left at a steeper angle. This proposal was based on the fact that the material under the dump was solid, the spoil material itself was coarse and relatively free of fines. It was felt that the underlying and dump material would be stable and the coarse surface material would prevent surface creep, thus the slope angle could be left at 30^{o} in some specific areas. After a year these specific areas had no sign of erosion and vegetation had established successfully. Obviously the steeper angle has to be a factor of the spoil material, but where possible this represents a considerable cost saving in leaving spoil material at this steeper angle.

After resloping the spoil, the standard approach is the sowing of seed and fertilizer by hand using cyclone seeders. Lately, the use of helicopters in seeding and fertilizing is becoming more prevalant. The area is then harrowed using very heavy duty harrows which are drawn across the slope. This procedure serves a dual purpose primarily covering the seed and secondly the harrows and dozer crossing the slope create a series of small terraces which aid in erosion control and contain surface water for use by vegetation.

The grass and legume species used are all agronomic and the mixture is the result of test plot and annual vegetation assessments of reclaimed sites over the life of the programme. The aim is to cover the spoil with vegetation as soon as possible to reduce erosion, provide organic material and to provide grazing areas for wildlife. Ideally through succession native species will invade the seeded areas. Questions have been raised as to the suitability of agronomic species over the long term. To date studies carried out on reclaimed sites at lower elevations up to 5,500 feet indicate that once established agronomic species continue to reproduce and in fact ground cover and plant biomass has been on the increase. At the higher elevations it may be necessary to introduce native grasses to provide a suitable vegetation on a continuing basis. It may also be necessary to include native seeds with the initial seeding.

One optimistic note is that a test plot established in 1971 on Harmer at an elevation of 6,900 feet has shown an increase in certain agronomic species over the life of the plot.

On dark spoil the seeds require covering to protect them during germination and the methods that have proved most successful are harrowing or providing a wood fibre mulch using a hydroseeder. This approach stresses the value of an initial cover of grasses. It is felt that once this cover has been achieved then native shrubs and trees which have been grown from seed or cuttings in the greenhouse and nurseries can be planted on site. These seedlings can be held in the nurseries until they are of a suitable size to be field planted. To date approximately 350,000 trees have been planted on reclaimed sites.

The application of fertilizer to established vegetation has been on an annual basis. No definite time limit has been established as to the number of years this may be necessary until the vegetation becomes self-sustaining. Too little is known about the use of added nutrients. A better understanding of the nutrient cycle of these plant communities will allow for a more efficient use of fertilizer. To this end a study was initiated to follow the flow of nutrients through the soil, plant, and detritus compartments of the nutrient cycle. Also being studied are nutrient cycles of adjacent native grasslands to compare the 'stable' communities with the introduced communities.

EXPLORATION

Since 1974, Kaiser Resources Ltd. has employed exploration techniques that differ greatly from the extensive land and water disturbing practices previously used. Once techniques such as seam tracing and trenching were used almost exclusively to provide geological information. The revised technique used at Kaiser eliminates the need for this and with the use of drillhole information and geological mapping, as well as planned access roads and adits, more geological information can be obtained with less unnecessary disturbance. Prior to any exploration disturbance taking place, all exploration proposals are plotted on sensitivity maps and aerial photographs. This enables Environmental Services personnel to evaluate the effects of the proposed work and to request alteration or elimination of undesirable proposals. In the field, all roads, drillsites, and adit sites are flagged and inspected prior to construction. This enables site specific changes to be made to avoid sensitive areas that did not show up on the sensitivity maps or aerial photographs. Once construction has been approved, experienced operators, most of whom have attended a Kaiser sponsered course on Environmental awareness and protective techniques in Exploration, carry out the work. Whenever accessible merchantible timber is encountered, pre-logging of the road right-of-way is carried out. Merchantible timber is decked and later sold to local mills. This technique avoids costly and dangerous slash abatement at a later date and provides a monetary return as well as the utilization of a natural resource.

Apart from pre-logging, supervision and monitoring of proposed and on-going exploration, reclamation of past exploration work is carried out by Kaiser's Environmental Services Department. Some of the work done includes slash abatement using powersaws and a woodchipping machine, ripping and seeding of dormant roads, backfilling of trenches, seam traces, test pits and adits, and re-establishment of watercourses.

CONCLUSIONS

Reclamation of a variety of mined land and exploration sites has been successful using techniques of resloping, seeding, planting, harrowing and fertilizing. Although the general approach to resloping is to aim at a maximum of 26^{0}, recent small scale attempts at 30^{0} have resulted in favorable revegetation levels.

Native trees and shrubs have been used successfully on reclamation projects, however some sites are not suitable for these plants because of changed soil conditions. On such sites, agronomic species of grasses and legumes are the only species used. The use of native species of grasses and legumes is being investigated at Kaiser. Present research on the subject in general indicates that it may be necessary to use native species more extensively at high elevations either in initial seeding or in supplementary seedings. This is expected to ensure the longevity of desirable species.

The techniques presently being used in the exploration-reclamation section, that is pre-planning of disturbances on sensitivity maps, monitoring and supervision of exploration work, resloping, terracing, ripping and seeding, and watercourse restoration are resulting in a more orderly and less damaging exploration program. Recent innovations widely used include the use of a woodchipping machine for slash abatement, pre-logging of exploration roads, terracing, and salvage of adit waste.

Most fundamental to the Reclamation program in general is pre-planning. The experience at Kaiser indicates that the most effective and productive approach to reclamation is with research programmes complementing the ongoing field programmes.

PAPER

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AGRONOMIC PROPERTIES AND RECLAMATION POSSIBILITIES FOR SURFACE MATERIALS ON SYNCRUDE LEASE #17

by

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ABSTRACT

Reclamation planning for tar sands mining and extraction operation differs greatly from that used in Alberta foothills and plains coal mines. One of the main differences is that the bulk of the surface materials to be placed and vegetated are spent tailings sand. On-site overburden materials suitable for amelioration of the sand consist of peat and glacial till. Tailings sand itself is too low in available moisture and nutrients to support vegetation without amendments. A landscape design concept is described that improves overall nutrient and moisture status of the sands and allows for vegetation diversity on the reclaimed land.

1. SYNCRUDE LEASE #17 SITE FEATURES

Syncrude Canada Ltd. Mildred Lake Project is located approximately 55 miles (40 km) north of Fort McMurray, Alberta, within the lower Beaver Creek watershed. One possible project layout is shown on Figure 1. Areas to be reclaimed will consist of the mining area, tailings pond, and associated lands. At least 5000 acres of land will need to be reclaimed (not including water surfaces). Figure 2 provides a schematic outline of steps in the mining and disposal of tar sands.

2. PRESENT LAND CAPABILITIES

Present land capabilities in the vicinity of the Mildred Lake Project can be summarized as follows:*

VEGETATION

The present non-industrial land uses surrounding the Syncrude Lease 17 are forest oriented, although the land is not highly productive from a forestry viewpoint. Two-thirds of the ground cover comprises non-commercial deciduous, softwood scrub, muskeg and hardwood scrub. The primary commercial species are white spruce *(Picea glauca)* and jackpine *(Pinus banksiana)*.

More specifically, the landscape of Lease 17 can be divided into eight plant communities plus water. Each of these landscape units has different land capabilities. Table 1 provides a resume of these units and their relative land capabilities on the basis of present land management in this part of Alberta.

WILDLIFE HABITAT

Present ungulate habitats primarily support moose *(Alces alces)*, but they also have capability for mule deer *(Odocoileus hemionus)*, white-tailed deer *(Odocoileus virginians)*, elk *(Cervus canadensis)*, woodland caribou *(Rangifer caribou)* and barren ground caribou *(Rangifer tarandus)*.

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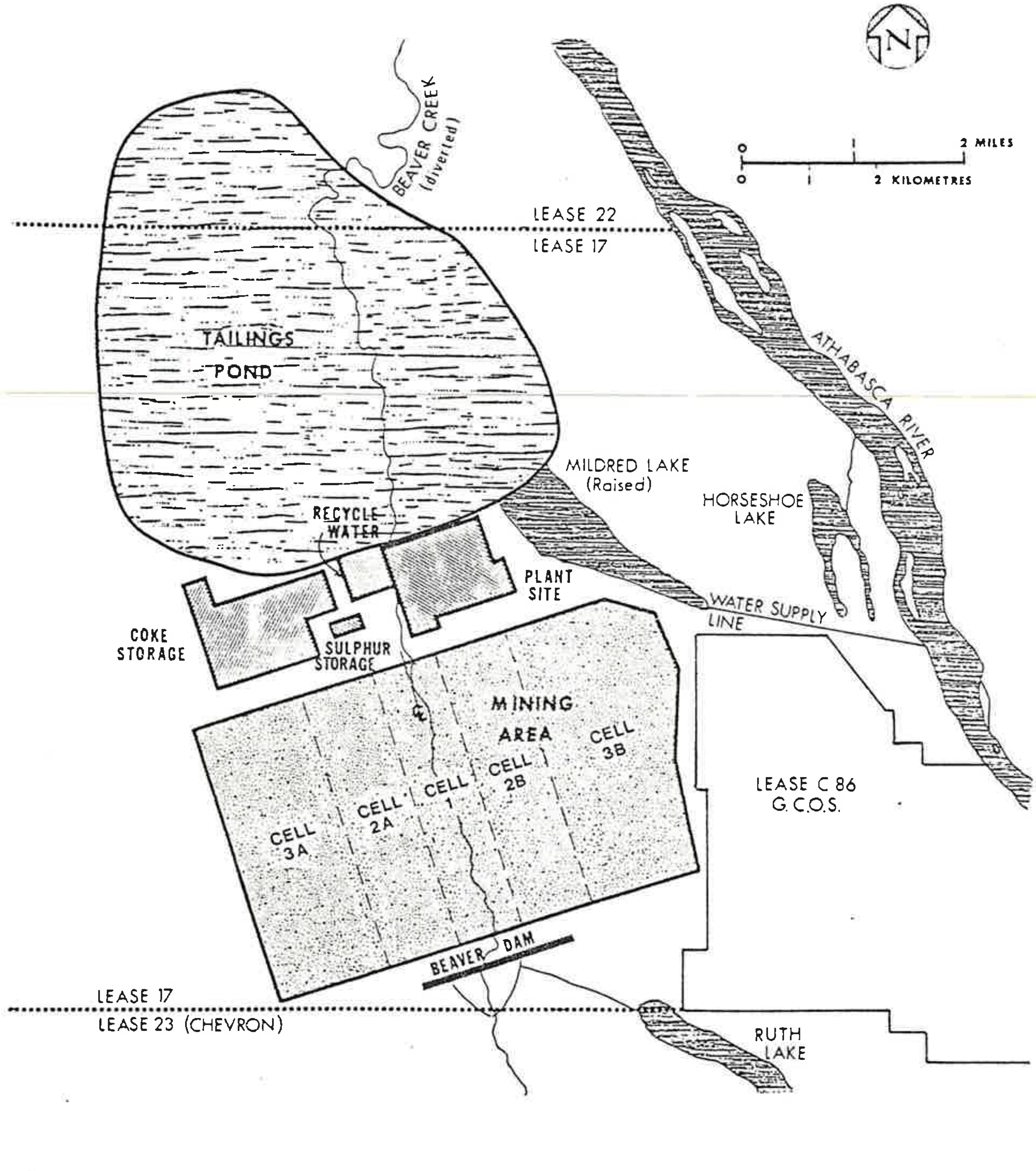
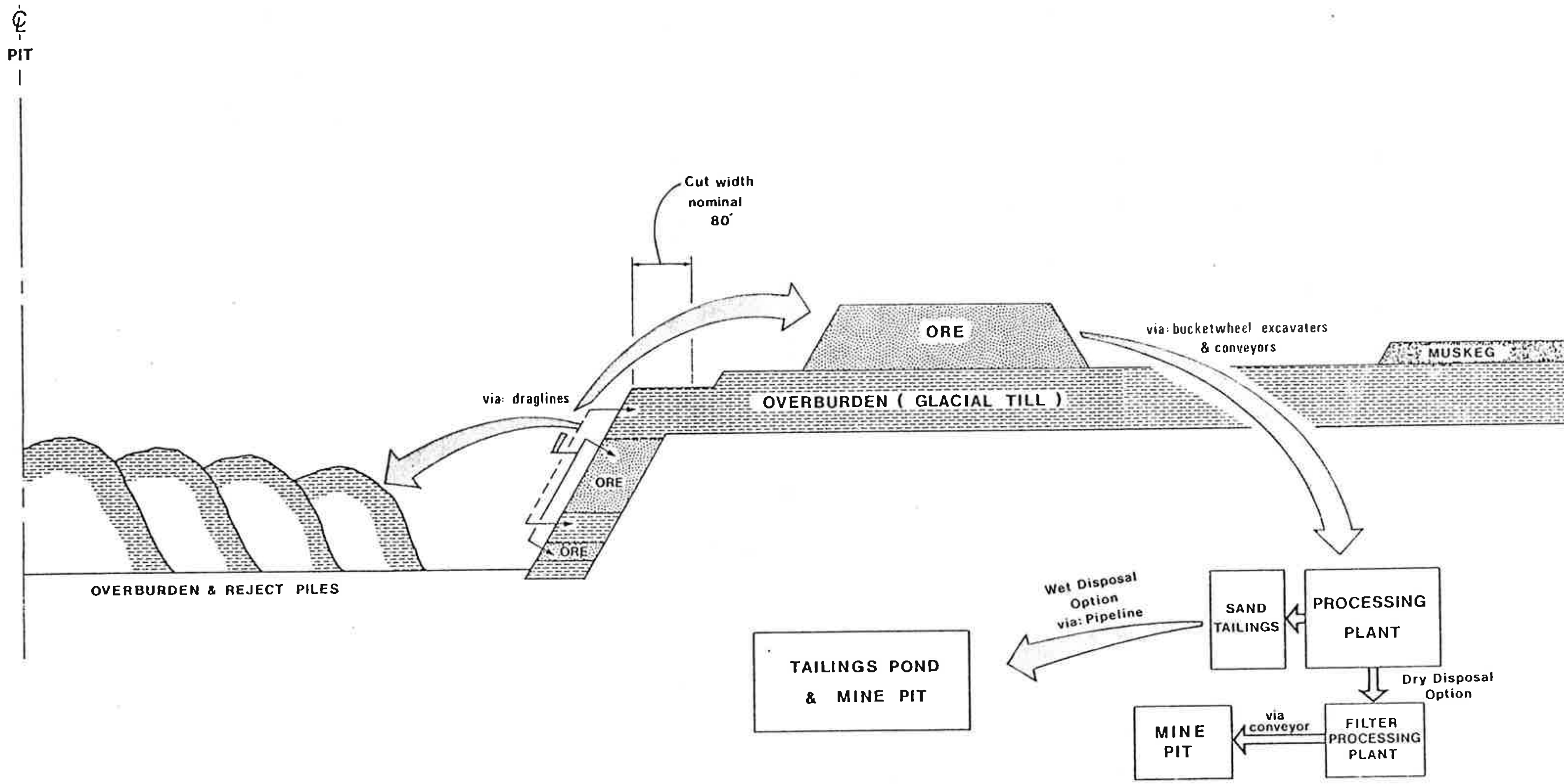
* Based in part on Syncrude Canada Ltd. 1973 Research Monographs 1973-1 and -2.



Syncrude Site Plan
(wet tailings disposal)

FIGUR



MINING AND DISPOSAL SCHEME

FIGURE 2

The highest quality moose winter habitats are found in pure aspen, white spruce-aspen, and riverine plant communities. Shrubs such as willow and red osier dogwood contribute to the importance of these stands for winter browse. Grasses and forbs in spruce-aspen types offer good potential for summer range for deer and elk.

Pine forests have limited value for wildlife except that lichens and moss offer potential food for caribou.

Boggy areas of willow - muskeg and treed muskeg are secondary sources of browse and are heavily hedged by rabbits.

Open water areas such as Mildred Lake and Horseshoe Lake have abundant stands of aquatic plants and are used by spring migrating waterfowl. A few beaver and other furbearers use the aquatic habitats and moose probably feed on aquatic vegetation during the later summer.

RECREATION

Hunting, fishing and scenic touring are the main recreational activities at present in the Athabasca area. A few campsites and parks are available but in general recreational facilities are absent or limited. The nearest provincial park at Gregoire Lake about 20 miles southeast of Fort McMurray is accessible by road.

Moose, deer, caribou, elk, grouse and ptarmigan are all popular game species.

The Beaver Creek watershed is not considered to be of high quality for sport fishing. Occasionally grayling and northern pike are caught.

3. RECLAMATION OBJECTIVES

Reclamation objectives in Alberta are determined by government regulations and by the traditional land use of a disturbed area. Provincial regulations require the reestablishment of a land capability at least as good as it was before land disturbance, and the traditional land use in the Athabasca oil sand region has been forestry oriented. Consequently the most typical choice of future land uses in the reclaimed areas are forestry, wildlife and recreation.

Table 1 RELATIVE LAND CAPABILITIES IN VICINITY OF SYNCRUDE LEASE #17 (Based in part on Syncrude Canada Ltd. 1974 Research Monograph 1974-3.)

Plant community or habitat type	Land capability		
	High	Moderate	Low
Jackpine		Wildlife	Forestry Recreation
Jackpine - aspen		Forestry Wildlife	Recreation
Aspen	Wildlife	Forestry Recreation	
White spruce - aspen	Wildlife	Forestry	Recreation
White spruce		Forestry Wildlife	Recreation
Riverine poplar - spruce	Wildlife	Forestry Recreation	
Black spruce		Wildlife Recreation	Forestry
Sedge Fen		Wildlife Recreation	
Open and shallow water	Wildlife	Recreation	

Apart from providing land for a specific purpose the basic objective of reclamation is the reestablishment of land and water resources for a variety of possible future uses. The most important factors limiting the variety of possible land uses are topography and drainage besides climatic limitations. Therefore the reclaimed land should be level or gently sloping with adequate drainage.

More or less level backfilled lands will be reclaimed for forestry and recreation uses with an average productivity equalling or better than that of the land before disturbance, while steeper slopes will be revegetated primarily for erosion control.

Engineering requirement will create some steeper slopes bordering the backfilled areas which will have land use limitations due to lower soil stability and access problems. However, these steeper sites together with possible poorly drained locations will add ecological variety for wildlife use.

4. SURFACE TOPOGRAPHY OF BACKFILLED MINE PIT

The topography of the backfilled mine pit will be determined by the method of tailings deposition. In case of hydraulic tailings disposal the surface will slope gently (about 5%) from the in pit dykes to the center of the mine pit cells creating a pattern of long flat hills and valleys.

An expected permeability rate of 10^{-3} cm sec^{-1} in the backfilled sand will result in a water table at a 20 m depth. An undulating land surface with a 30 m elevation difference between the valley and the crest will intersect this groundwater table providing wet land in the valley bottoms.

This type of landscape will provide well to moderately well drained soils on the crests and hillsides and poorly drained land in the valley bottoms. Most of this land will support forest communities of medium productivity while the depressions would support marsh plants as shown in Figure 3.

CONCEPTUAL LANDSCAPE DESIGN FOR MINE PIT DISPOSAL AREA

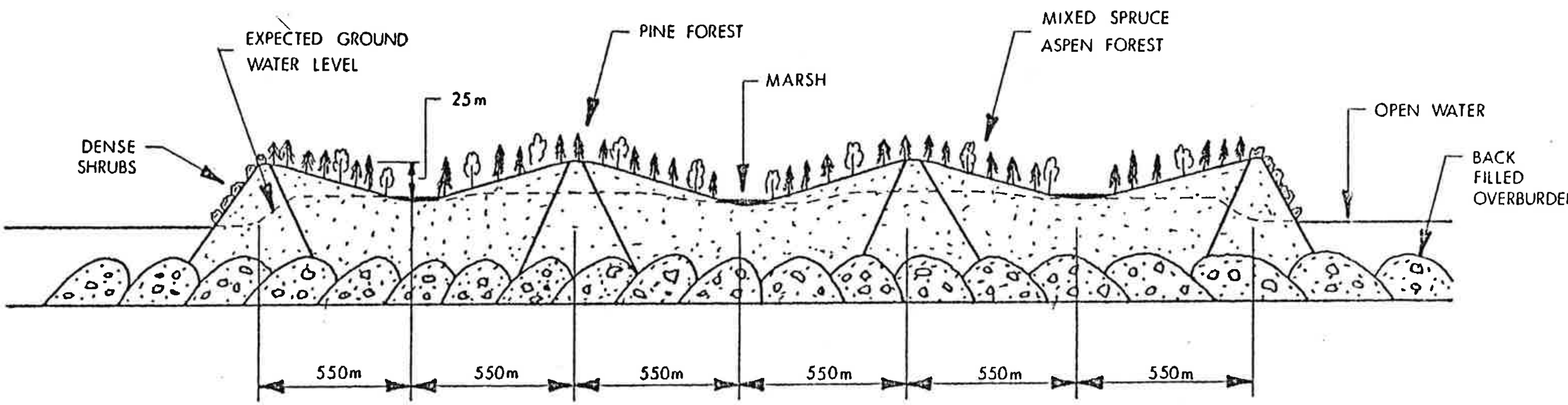


FIGURE 3

Relatively steep 3:1 slopes will occur on the outside dyke surfaces where vegetation will be established mainly for erosion control. These sand dykes will be free draining, with a groundwater surface about 70 m back from the dyke surfaces, causing no problems with saline groundwater discharge.

5. SOIL RECLAMATION

The tailings sand is unsuitable as a plant growth medium when first deposited in dykes or disposal areas. After process water drains from the sand, its toxicity is lost but it remains deficient in several basic physical and chemical properties required for plant growth. Table 2 provides a comparison between key properties of spent tar sands and various textural groupings of existing surface soils on the Syncrude lease.

The presence of soluble sodium in the spent sands is probably its only undesirable chemical property. Since the sands have almost no cation exchange capacity (CEC), soluble sodium is easily drained or leached out. If alkaline process water ponds on or seeps to the surface of the sands, it may raise sands to undesirable sodium levels. Where free drainage and leaching of the surface is possible, sands should be suitable for amelioration and seeding the same year as they are placed.

Tailings sand is deficient or low in nitrogen, organic matter and CEC by comparison to present surface soils on the property. Present data on surface soils (Table 2) that might be used for amelioration of sands indicate that they also are deficient or low in major nutrients. Fertilization will be required to encourage early plant growth in the new soil. As a first step toward long term fertility it will be necessary to build up sufficient CEC in the surface horizons of the new soil to retain soluble ions. Further, the new soil must develop some of the microbiological properties normally found in forest soils including the ability to recycle nitrogen and to decompose organic matter. This biological activity is not subject to amelioration (e.g. by addition of manure) in the present system and will have to build up as vegetation becomes established and organic material accumulates in the soil.

Tailings sand has only about 1% available moisture as compared to about 10% in loamy soils on Lease 17. Assuming the sand weighs about 100 lbs./cu. ft., the upper foot of sand could supply 1 lb. or about 0.2 inches (.5 cm) of water between rainstorms. Daily transpiration requirements vary with climatic conditions during the growing season, but an established covercrop of grass and legumes could use up to 10 inches (25 cm) of water in a growing season (i.e. about 0.1 inches/day). Allowing a day for free draining soil in the root zone to reach field capacity, crops on tailings sand would experience drought within 3 or 4 days after a rainstorm. Increasing the available moisture to 3 or 4% will extend the period between rainstorm and drought to as much as 15 days. Since rainstorms are common during the summer months in this area, 4% available moisture should be adequate for cover crop establishment.

Peat and glacial till are the two materials available on Lease No. 17 to improve the tailings sand before seeding the initial covercrop.

PEAT

As a soil amendment, peat adds organic matter, increases cation exchange capacity and available moisture, lowers bulk density and helps to maintain pH values at or below neutrality. The most desirable peat would have the following properties:

- pH of 7.0 or less
- cation exchange capacity of at least 100 meq/100 g dry wt.
- at least 1.0% dry weight of total nitrogen
- SAR less than 6
- a moderately fine fibrous structure
- relatively small amounts of wood or mineral matter,

A guideline for amelioration of tailings sand is that enough peat be added to bring the sand to a 2% organic matter content on a dry weight basis. Therefore, about 2 lbs. of dry peat would to be incorporated into 1 cu. ft. (100 lbs.) of sand. This means an application of some 40 metric tons of dry peat per acre. The volume of peat required to obtain this rate will depend upon its water content at the time of application.

Present information indicates that peat on Lease 17 can have a cation exchange capacity (CEC) as high as 200 meq/100 g. Based upon an average value in the peat of about 150 meq/100 g, the increase in CEC to the sand from peat alone would amount to about 3 meq/100 g. if sands are raised to 2% organic matter. Although this is not a large increase in comparison to agricultural soils, it should have a significant effect on the nutrient status of the sand.

CLAY TILL

Clay till can be used to increase available moisture and cation exchange capacity, reduce free drainage and promote the formation of soil structure. While peat may provide the above effects for some years, long term soil improvements will be achieved by the addition of till. Available data indicates the surface soils on Lease 17 contain from 10% as much as 60% clay and it is this fraction that provides most of the CEC on a dry weight basis. CEC of till soils on the lease area range from 3 to 40 meq/100 g. depending on their clay content. If till alone were used to raise the CEC of the tailings sand, material with a CEC of at least 20 meq/100 g. would be required, which would probably mean a clay content of about 50%. Six inches (15 cm) of till would need to be mixed with 6 inches (15 cm) of sand to obtain a CEC of 10 meq/100 g. in the upper foot of soil. To lower the requirements for till a mixture of till and peat will be used.

If clay till were used to increase the available moisture in the tailings sand to the 4% level mentioned above, the till/peat/sand mixture would need to have about 10% clay. About 2½ inches (6 cm) of 50% clay till would need to be mixed with 10 inches (25 cm) of sand to give the desired loamy sand texture. However, to satisfy long term fertility needs, 4 inches (10 cm) of till will be applied to the sand. This mixture would then require addition of peat. Field trials will be conducted to confirm the feasibility of mixing these materials with a rotovator under different moisture conditions and slopes. We estimate about 400 m^3 of clay till would be required per acre of reclaimed land to reduce the moisture deficit and improve the nutritional properties of tailings sands.

6. RELATED AGRONOMIC PRACTICES

TILLAGE

As discussed above, 4 inches (10 cm) of till and about 39 metric tons of dry peat is required per acre of reclaimed land. On sloped dykes till and moist peat would be dumped at the top of each lift and spread downslope with crawler tractors and drags to obtain an even distribution. The till and peat would then be rotovated into the sand to provide a mixed surface horizon. On a 3:1 slope a self-powered rotovator may need to be towed across the slope from cables attached to tractors at the top and bottom of each lift. Alternatively, a tractor mounted rotovator could be operated downhill with the tractor returning to the top with the rotovator idling.

On nearly level surfaces the till and peat could be dumped in small piles and spread with a drag using a farm or crawler tractor. The rotovator would be attached directly to the tractor for tilling. It is estimated that peat could be spread and tilled at the rate of about 10 acres/day on level ground using two tractors for spreading and one for rotovating. About half of this rate could be maintained on 3:1 slopes and two crawler tractors may be required for rotovating.

Field trials are required to work out the most practical combinations of equipment and soil amendments to obtain specific physical and chemical properties in the new soil. These trials should be undertaken at an early stage so that long term reclamation planning can be based upon proven field methods.

After rotovating, the soil will probably require packing. This operation may be done separately or in conjunction with seeding. The packer must operate across the slopes to reduce the erosion potential on the new soil. Operational trials will also be required to determine optimal seeding methods, i.e. by broadcasting or drilling. On level surfaces drilling and packing with standard farm implements should prove adequate for grasses and legumes. On sloped surfaces broadcasting and harrowing may be more suitable. Details of seeding rates, timing, depth, mixtures, implements etc. are best determined in field trials.

FERTILIZERS

Fertilizer will need to be applied at the time of seeding and for several years thereafter to promote plant growth. Since fertilizer will be easily leached from the new soil, two applications per year may be necessary. Fertilizer will be rapidly taken up by plants when growth is initiated in the spring and during rapid growth in the summer. Fertilizer rates, timing and mixtures should be worked out in field trials. First year applications should consist of balanced mixtures to ensure normal top and root growth. In subsequent years a higher percentage of nitrogen will be required than of phosphorus or potassium.

Fertilizer is relatively inexpensive by comparison to the cost of soil preparation and seeding; therefore, applications as high as 400 lbs./acre should be considered in the first few years. After adequate cover crop has been established, fertilization would be phased out. When converting to forest types it may be necessary to fertilize tree seedlings for one or two years after transplanting.

PEAT AND TILL INVENTORY

At present there is no quality or quantity inventory of the peat and till materials on the property that can be used as soil amendments. The report by Regier in 1976 is the only information we are aware of on this topic. This work gives a good indication of the range of qualities in the till but provides no quantity estimates. An inventory is required to plan the removal and stockpiling of suitable peat and till materials.

To correct this deficiency Syncrude is currently conducting an overburden survey and a soil survey in the lease area. The surveys will be followed up by chemical and physical soil analyses to obtain quality information on the inventoried materials.

The soils inventory and field trials will remove many of the uncertainties that still exist in the operational aspects of reclamation. This work will also be essential in demonstrating to government agencies that reclamation plans can in fact be implemented.

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PAPER

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THE USE OF PEAT, FERTILIZERS AND MINE OVERBURDEN TO STABILIZE STEEP TAILINGS SAND SLOPES

By Michael J. Rowell

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ABSTRACT

The revegetation of tailings sand slopes that result from tar sands extraction pose many problems. The tailings material has a low moisture holding capacity, contains low amounts of plant nutrients and is potentially very erodable.

Large areas of tailings material have been successfully revegetated by Great Canadian Oil Sands Limited by employing a 15 cm thick amendment of peat on the surface. Even 5 years after seeding with grasses and legumes these areas must receive regular fertilization to maintain a good surface cover.

In new experiments the tailings sand surface was amended with peat or peat/overburden mixtures. A good surface cover was rapidly established by the addition of N, P, K and S containing fertilizers. Most efficient use of the fertilizers occurred when 80 kg-N, 35 kg-P, 75 kg-K and 20 kg-S were added per hectare rather than when larger amounts were added. Rapid plant growth enabled erosion to be kept at a minimum. Losses of plant nutrients through leaching and surface water runoff were not serious in relation to the amounts added as fertilizer. Additional application of fertilizer later in August did not increase dry weight yield but did enhance nutrient uptake into the plant tops. Dry weight production of tops and roots was about the same in the first year of growth. Root growth was largely restricted to the surface 15 cm of peat and overburden.

THE USE OF PEAT, FERTILIZERS AND MINE OVERBURDEN TO STABILIZE STEEP TAILINGS SAND SLOPES

By Michael J. Rowell*

Norwest Soil Research Ltd.

1. INTRODUCTION

Research studies into the revegetation of steep tailings sand slopes resulting from tar sand extraction in the Fort McMurray area of Alberta are currently into their third year. Detailed reports of the first two years of study are available as monographs[1,2]. This paper is concerned with some of the field scale investigations carried out at the Great Canadian Oil Sands Limited (GCOS) plant in Fort McMurray where active reclamation has been in progress for several years.

2. STUDY OF PREVIOUSLY REVEGETATED TAILINGS SAND SLOPES

During the summer of 1975 field scale studies centred upon investigation of ways of improving steeply sloping areas of tailings sand that had already been seeded with grasses and legumes. One such area had received a surface application of about 15 cm of peat during the winter of 1970/71. In the spring of 1971 the area was seeded with the seed mix shown in Table 1. Between May 1971 and July 1974, the area received 8 small additions of fertilizer that amounted to a total of 222 kg-N; 110 kg-P and 150 kg-K per hectare. Revegetation had been successful in that a protective plant cover had been established. However, nutrient deficiencies made it difficult to sustain a healthy growth of plants throughout the growing season. During periods of heavy rainfall there

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TABLE 1. Seed mix used to revegetate a tailings sand slope at the GCOS plant at Fort McMurray, Alberta

Species	Percentage by volume
Brome Grass (Bromus inermis)	33
Crested Wheat Grass (Agropyron cristatum)	24
Creeping Red Fescue (Festuca rubra)	15
Sweet Clover (Melilotus sp.)	14
Alsike Clover (Trifulium hybridum)	14

Added at a rate of 30 lb/ac (about 27 kg/ha)

was a danger of the peat mantle becoming undercut resulting in serious erosion of the slope.

In the early summer of 1975 most of the plant cover was made up of Creeping Red Fescue and to a lesser extent, Brome Grass. Crested Wheat Grass and the legumes were almost absent. Addition of fertilizers to an experimental area resulted in both qualitative and quantitative improvements in the sward. The different fertilization programs involved once or twice yearly additions of N, P, K and S containing fertilizers at rates varying from no addition up to 290 kg-N; 36 kg-P; 145 kg-K and 29 kg-S per hectare. Tables 2, 3, and 4 show plant yields and nutrient uptake during 1975 and 1976. The results indicated that although large increases in plant productivity could be induced through addition of nutrients, the area could not be considered self sustaining if fertilization was discontinued. For instance, treatments that received large additions of fertilizer in 1975 but none in 1976 did not continue to yield well in 1976. Carry-over of fertilizer nutrients from one year to the next seemed to be short lived and plants showed nutrient deficiency symptoms (especially

TABLE 2. Improvement of a 5-year revegetated tailings sand dike slope amended with 15 cm of peat

	Fertilizers added (kg/ha) 1975				1976				Plant dry weight yield (kg/ha)	
	N	P	K	S	N	P	K	S	1975	1976
To	0	0	0	0	0	0	0	0	980	2390
T1	71	18	71	7	71	18	71	0		3760
T1A	143	36	71	14	71	18	71	0	3670	3710
T3	143	36	143	14	0	0	0	0		2600
T3A	286	36	286	29	0	0	0	0	4040	2910
T5	35	9	18	32	34	9	18	7	2670	3760

Between May 1971 and July 1974 the area received 222 kg-N, 110 kg-P and 150 kg-K per hectare.

TABLE 3. Nitrogen uptake into plant tops on a 5 year revegetated tailings sand dike slope amended with 15 cm of peat.

	Nitrogen uptake (kg/ha) 1975	1976
To	9	22
T1	49	55
T3	90	42
T5	14	68

nitrogen) later in the summer of 1976. Frequent small additions of fertilizer were more beneficial than larger yearly or biennial applications. A limited study of root growth indicated that, over the 5 year revegetation period, root tissues had accumulated to the extent that root:shoot ratios varied between about 4:1 to 7:1. Turnover of nutrients bound up in roots could be expected to be much slower than for the above ground tissues.

The growth of roots was largely limited to the surface layer of peat. This inability to get roots to penetrate significantly into the tailings sand layers below was considered a serious deficiency.

3. ASSESSMENT OF RECLAMATION MATERIALS

The possible readily available surface material amendments were characterized with respect to their chemical, physical and biological properties. The most promising materials were surface peats and mine overburdens. The results of analysis of some materials are shown in Table 5, 6 and 7.

Freshly deposited tailings sand has an alkaline reaction and a high content of soluble sodium resulting from the caustic bitumen extraction process. The soluble salts leach out readily and within 1 or 2 years the tailings sand has a nearly neutral to slightly alkaline pH. Properties of low moisture retention, low available plant nutrients and a high erosion potential make the tailings sand a very poor surface to revegetate directly without any amendment.

The characteristics of mine overburdens vary somewhat depending upon location. Although they are also sandy in nature, the presence of some clay makes them less erodable than the tailings sand. The natural levels of soluble salts are quite high due to the presence of moderate

TABLE 5. Properties of tailings sands, peats and overburden - (I).

	pH	Cond. mmhos/cm	Soluble Cations (meq/100 g) Na	Ca	K	Mg	Organic C (%)	Total N (%)	Extr. Bitumen (%)
Tailings sand (fresh)	9.7	1.17							
Tailings sand (weathered)	6.2	0.46	0.026	0.040	0.003	0.026	0.33	0.03	0.18
Overburden #2	7.8	2.66	0.71	0.51	0.051	0.28	1.00	0.08	0.15
Peat (pH 4.1)	4.1	0.16							
Peat (pH 5.4)	5.4	0.29							

TABLE 6. Properties of tailings sands, peats and overburden - (II).

	Available Nutrients (ppm) NH_4-N	NO_3-N	P	K	SO_4-S	C.E.C. meq/100 g	Exch. + Sol. Cations meq/100 g Na	Ca	K	Mg
Tailings sand (weathered)	1.5	1.3	2.3	9	7.0					
Overburden #1	0.2	0.0	3.5	33	278	3.9	0.43	12.0	0.64	1.70
Overburden #2	14.0	2.2	1.8	205	107	ND	2.76	8.4	0.53	2.14
Peat (pH 4.1)	0.0	0.0	4.0	130	460	127	0.65	33.3	3.80	9.00
Peat (pH 5.4)	41.6	53.8	2.8	233	10.4	ND	0.73	52.8	0.60	0.61

ND - not determined

TABLE 7. Properties of tailings sands, peats and overburden - (III).

	Particle size distribution			Moisture	Bacteria	Fungi	Algae
	Sand (%)	Silt (%)	Clay (%)	1/3 Bar (%)	x 10^6/g	x 10^6/g	x 10^6/g
Tailings sand	96	1	3	1.4	0.15	0.10	0.0
Overburden #1					1.30	0.20	6.2
Overburden #2	79	12	9	9.9	14.00	0.20	0.0
Peat (pH 4.1)				250	2.20	130	9.8
Peat (pH 5.4)				72.0			

amounts of sodium carbonate and sulfate. However, the electrical conductivity is rarely high enough to indicate a serious concern in the overburden's ability to support plant growth. In comparison to the tailings material, overburdens are very well buffered around their neutral to mildly alkaline pH. The overburdens are also a good source of available potassium and sulfur.

TABLE 8. Water holding characteristics of tailings sand, peat, overburden and mixes of these materials

	Moisture (%) 1/3 bar	Moisture (%) 15 bar
Tailings sand	1.8	0.9
Overburden	9.9	4.1
Peat (pH 5.4)	72.0	43.6
Tailings sand/peat (1:1 v/v)	15.8	12.5
Tailings sand/peat/overburden (1:1:1 v/v/v)	10.7	4.9

Both acidic and neutral peats are found in the mining area. They are generally low in available plant nutrients, especially nitrogen and phosphorus, although levels do vary with the source of the peat. The main advantages of peats in reclamation are high water holding characteristics and a good cation exchange capacity. Table 8 shows the beneficial effect on water holding capacity by the inclusion of peat in some different soil mixes. In comparison to tailings sand and many overburdens, the peats contain high numbers of microorganisms which are necessary in mediating transformations that result in the mineralization of organic materials and the release of available plant nutrients. The inoculation of the revegetation surface with micro-organisms from the peat probably represents one of the more important long term effects of soil surface amendments to the tailings sand slope.

4. FIELD RECLAMATION EXPERIMENTS IN 1976.

Work with different soil mixes in growth chamber experiments was carried out in 1975. Results showed that, as long as optimum moisture and nutrient conditions could be maintained, tailings sand, peat, overburden, lean tar sands and various mixes could all support plant growth. Particularly encouraging results were obtained with tailings sand/peat and tailings sand/peat/overburden mixes.

Using the data from growth chamber studies and material characterization, new revegetation field trials were started in 1976. The basic objectives of the experiments were to study the success of revegetation on tailings sand slopes using different peat and overburden amendments and different fertilizer programs. Investigations also concerned ways of improving root penetration and assessment of the performance of several grass and legume species. Once again the location of the experiments was the tailings pond dike at the G.C.O.S. plant at Fort McMurray.

The design of the main experiment is shown in Figure 1. The various main and sub-treatments are shown below.

<u>Main treatments applied to the tailings sand surface</u>

	fertilizer additions in kg/ha				
	N	P	K	S	
Treatment A	80	35	75	20	Applied in June
B	150	40	150	20	Applied in June
C	150	40	150	20	Applied in June
	150	40	150	20	Applied in August

Fertilizer was added as 21-0-0, 11-55-0, 34-0-0 and 0-0-62. Treatments B and C received one application of finely ground limestone at 5 tonnes/ha in June 1976.

Subtreatments applied to the tailings sand surface

1. 15 cm of peat applied to the tailings sand surface
2. As 1. with contour trenches
3. As 1. with "Aquatain" soil stabilizer
4. As 1. with "Bitumuls" soil conditioner
5. 5 cm overburden applied over 15 cm of peat (untilled)
6. 10 cm overburden tilled into 15 cm of peat
7. 5 cm overburden tilled into 15 cm of peat
8. As 1. but not seeded until October, 1976.

Subsequent discussions will be limited to treatments 1, 5, 6 and 7 only.

The seed mix used is shown in Table 9. Seeding was completed on July 16, 1976.

A device to intercept runoff water and eroded soil was set up on some of the experimental treatments. The top of the plot was boarded off to prevent runoff water from the areas upslope from being collected. Two wooden boards were joined together to form a 'V' shape so that the opening produced was exactly one meter across. The boards were sunk about 8 cm into the ground at the bottom of the plot. The apex of the 'V' was located so that it collected from a 5 meter length of slope. A polythene funnel was buried at the apex so that the mouth was flush with the soil surface. A fine mesh screen was glued into the mouth to prevent

TABLE 9. Seed mix used in a revegetation experiment on a tailings sand slope at the GCOS plant, Fort McMurray

Species	Percentage Composition by weight
Altai Wild Rye	3.5
Streambank Wheat Grass	15.0
Smooth Fescue	16.0
Hard Fescue	3.0
Pubescent Wheat Grass	14.0
Slender Wheat Grass	12.0
Western Wheat Grass	3.5
Red Top	0.5
Kentucky Blue Grass	1.5
Lupine	8.0
Cicer Milk Vetch	6.0
Sanfoin	10.0
Alfalfa Rhizoma	6.0

Pendek Oats added at 40 kg/ha.

Seed, including oats, was added at a rate of 90 kg/ha soil from passing through. A closed 5 gallon plastic bucket was used as a reservoir to store the runoff water that was collected. It was connected to the funnel by polythene tubing and the pail was buried deep enough to allow water to freely run in under gravity. Water was collected from the reservoir at intervals throughout the summer and was analyzed for available N, P, K and S and for pH and conductivity. Eroded soil was also collected from the same collection area. Estimates were made of total soil erosion losses and of mineral nitrogen losses in eroded soil.

Leaching losses from the plots were estimated by using double pail lysimeters. These consisted of a 5 gallon plastic pail buried flush with the soil surface into which was lowered an identical pail filled with the required soil mix. Small holes had been drilled in the bottom of the inner pail which allowed water to drain out and collect in a thick polythene bag fastened around the inner pail. The lysimeters were individually seeded and fertilized at the same rates that were used on the plots. Leachate was analyzed for available nutrients, pH and conductivity.

Table 10 shows the results of soil analysis in June after peat and overburden had been applied but before fertilizer, lime and seed had been added.

The addition of peat resulted in a surface pH of 6.6 while inclusion of overburden increased the pH by up to 0.5 of a unit. Electrical conductivity was highest where overburden was added in addition to the peat. Even so, the values were not high enough to effect seed germination or subsequent plant growth. Moderate levels of mineral nitrogen occurred

TABLE 10. Soil analysis of the 0 - 15 cm depth in June, 1976.

Treatment	pH	Cond. (mmhos/cm)	NH_4-N	NO_3-N	P	K	SO_4-S
			(ppm)				
1. 15 cm peat	6.6	0.54	16	4	2	12	37
5. 5 cm overburden over peat	6.8	1.47	25	15	2	93	164
6. 10 cm overburden tilled into peat	7.1	1.54	21	10	2	65	164
7. 5 cm overburden tilled into peat	7.0	1.36	19	9	2	64	114

(Values above are means of plots to receive fertilizer treatment A. However, they are representative of the entire area.)

in the soils at this time. Ammonium nitrogen was more prevalent than the nitrate form. Phosphorus was very low in all four treatments. Potassium was very low where only peat had been added as an amendment. Higher values occurred in treatments 5, 6 and 7 due to the presence of the overburden. Levels of sulfate were adequate in terms of plant need in all the treatments. The highest amounts were found with the overburden treatments.

In September shoot and root samples were taken from each treatment to determine dry weight yields and nutrient uptake. The results for fertilizer treatments A and C are shown in Table 11. Yield differences between the two fertilizer programs and between subtreatments was not statistically different for the first season's growth. Production varied between 2460 and 3930 kg/ha for tops and between 1650 and 2810 kg/ha for root tissues. The oats, which was included as a nurse crop, made up the majority of the dry weight yield (see Table 12). In most instances the cover provided by the grass and legumes alone would have been adequate in terms of surface erosion control.

There were significant differences in the uptake of nutrients between the different fertilizer programs (see Table 13). Where extra fertilizer had been added in August (treatment C) the uptake of N, P and K into shoot tissues was increased although the amount taken up into root tissues was generally unaffected.

Soil analysis in September (see Table 14) showed that levels of N, P and K were low in treatments which received the lowest fertilization rate (80 kg-N, 35 kg-P, 75 kg-K and 20 kg-S per hectare in June). In treatment C (150 kg-N, 40 kg-P, 150 kg-K and 20 kg-S per hectare in June

TABLE 11. Plant dry weight yields - 1976.

Treatment	Tops	Roots
	(kg/ha)	
Fertilizer rate A		
1. 15 cm peat	2930	2810
5. 5 cm overburden over peat	3410	1690
6. 10 cm overburden tilled into peat	3930	2210
7. 5 cm overburden tilled into peat	3260	ND
Fertilizer rate C		
1. 15 cm peat	3040	1570
5. 5 cm overburden over peat	3430	1650
6. 10 cm overburden tilled into peat	3610	1900
7. 5 cm overburden tilled into peat	2460	ND

ND - not determined

TABLE 12. Distribution of plant types

Treatment	% of dry weight yield		
	Oats	Grasses	Legumes
Fertilizer rate C			
1. 15 cm peat	85	13	2
5. 5 cm overburden over peat	93	6	2
6. 10 cm overburden tilled into peat	91	7	2

TABLE 13. Nutrient uptake in plant tops and roots.

	Tops N	Tops P	Tops K	Tops S	Roots N	Roots P	Roots K	Roots S
	kg/ha				kg/ha			
Fertilizer rate A								
1. 15 cm peat	59	8	59	7	32	25	27	7
5. 5 cm overburden over peat	69	8	70	6	20	12	14	3
6. 10 cm overburden tilled into peat	81	9	79	6	20	14	13	4
7. 5 cm overburden tilled into peat	67	10	73	7				
Fertilizer rate C								
1. 15 cm peat	76	10	86	5	22	17	12	4
5. 5 cm overburden over peat	88	11	95	15	25	20	21	5
6. 10 cm overburden tilled into peat	86	10	110	6	23	17	25	4
7. 5 cm overburden tilled into peat	67	9	81	4				

TABLE 14. Soil properties in September - 1976.

	pH	Cond. mmohs/cm	NH_4-N (ppm)	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)
Fertilizer treatment A							
1. 15 cm peat	6.3	0.60	2	1	7	14	13
5. 5 cm overburden over peat	6.4	1.24	4	1	3	81	156
6. 10 cm overburden tilled into peat	7.0	1.23	2	1	6	54	135
7. 5 cm overburden tilled into peat	6.9	1.29	2	1	7	55	65
Fertilizer treatment C							
1. 15 cm peat	6.6	1.75	3	107	13	121	172
5. 5 cm overburden over peat	6.8	1.75	12	86	18	180	116
6. 10 cm overburden tilled into peat	7.0	2.60	3	85	26	161	103
7. 5 cm overburden tilled into peat	6.8	2.00	6	66	16	124	106

and August) available nutrients were more abundant. Mineral nitrogen occurred primarily as nitrate and some leaching losses could be expected during the fall and early spring. The pH of the different treatments showed the same relative trend observed in June with the overburden treatments showing a slightly higher pH than the peat-only treatments. The addition of lime resulted in a small increase in pH which had been reduced slightly by the addition of fertilizer in August. Similarly the extra fertilizer addition produced higher soil electrical conductivities. Values ranged from 1.75 mmhos/cm in the peat-only treatment to between 2.00 and 3.00 mmhos/cm in the overburden amended treatments. Although these values are moderately high they would not be expected to seriously affect the growth of the plant species used.

An approximate balance sheet of nutrient uptake and transfer can be drawn up using the data from plant and soil analysis and from lysimeter and runoff studies. Table 15 shows the estimates of soil erosion and mineral nitrogen losses in eroded soil. Although erosion was more severe in the overburden amended plots, in no case could the effect be considered serious where a plant cover had been produced. In contrast in treatment 8 which received a 15 cm application of peat but was not seeded until October, erosion was serious enough in places to warrant some repair work on the plots.

In relation to the amounts added as fertilizer, mineral nitrogen losses in eroded soil were minimal.

All the different surfaces involved (ie. tailings sand, peat, overburden and their mixes) have high water infiltration characteristics (21.6 to 30.5 cm/hr). As a consequence of this high absorptive capacity

TABLE 15. Estimates of soil erosion losses.

Treatment	Soil lost (cm)	Mineral nitrogen losses kg-N/ha
Fertilizer treatment C		
1. 15 cm peat	0.24	1.0
5. 5 cm overburden over peat	0.69	1.2
6. 10 cm overburden tilled into peat	0.81	1.4
7. 5 cm overburden tilled into peat	0.32	0.7

only between 0.79% and 2.5% of the intercepted rainfall was collected as runoff (see Table 16). The amounts of nutrients lost were also small in relation to the quantity added as fertilizer. Phosphorus losses were lowest. Nitrogen losses varied between 0.4 and 1.4 kg-N/ha with most of this composed of nitrate. Potassium and sulfate sulfur runoff losses were higher than for N and P. Losses were greatest in the overburden amended plots presumably due to the naturally higher levels of soluble sulfate and potassium in these materials.

Leaching losses were greater than runoff losses (see Table 17). Between 15.7% and 28.9% of the intercepted rainfall leached below the 30 cm depth. Nutrient losses were consistently higher in the overburden amended treatments.

Between 1.3 and 2.0 kg-N/ha was lost under fertilizer regime A while between 3.1 and 5.6 kg-N/ha was lost through leaching with treatment C (high June and August applications). Most was lost as nitrate. Phosphorus was practically immobile and losses accounted for less than

TABLE 16. Surface water runoff losses.

Treatment	Water Runoff (l/m^2)	Nutrient Losses (kg/ha) N	P	K	SO_4-S
Fertilizer rate C					
1. 15 cm peat	1.2	0.4	0.1	0.6	0.9
5. 5 cm overburden over peat	3.9	0.4	0.4	4.1	3.0
6. 10 cm overburden tilled into peat	4.5	1.4	0.1	3.5	3.4
7. 5 cm overburden tilled into peat	2.0	1.4	0.1	1.9	2.0

Addition in rainfall (kg/ha) during June-September 1977, 1.1 N, 0.0 P, 0.3 K and 4.5 S.

Intercepted rainfall during June-September 1977 = 178.5 l/m^2

TABLE 17. Estimates of water leaching losses.

	Water Leaching (l/m^2)	Nutrient Losses below 30 cm (kg/ha) N	P	K	SO_4-S
Fertilizer rate A					
1. 15 cm peat	29.4	1.7	0.1	1.1	9.8
5. 5 cm overburden over peat	34.2	2.0	0.1	2.3	31.1
6. 10 cm overburden tilled into peat	32.1	1.4	0.1	1.4	7.5
7. 5 cm overburden tilled into peat	33.8	1.3	0.1	1.1	7.7
Fertilizer rate C					
1. 15 cm peat	28.1	4.7	0.1	1.9	9.8
5. 5 cm overburden over peat	33.8	5.2	0.1	5.6	15.6
6. 10 cm overburden tilled into peat	30.5	5.6	0.1	5.0	11.9
7. 5 cm overburden tilled into peat	51.5	3.1	0.1	2.8	12.4

0.1 kg-P/ha during the summer. Potassium losses were approximately the same as for nitrogen. Amounts varied between 1.9 and 5.6 kg-K/ha at the highest rate of fertilizer addition and between 1.1 and 2.3 kg-K/ha at the lower rate. Sulfate sulfur losses were highest and most variable. Values recorded varied between 7.5 and 31.1 kg-SO_4-S/ha. Sulfate may originate from natural soil sulfates, fertilizer-S, and atmospheric sources. An estimated 4.5 kg SO_4-S/ha were deposited in rainfall between June and September. The majority of this could be expected to result from stack emissions.

Table 18 summarizes the uptake and transfer of nitrogen in revegetation treatments 1 and 5 during the summer of 1976. Most efficient use of fertilizer was achieved at the lower rate of addition. Differences between the two subtreatments 1 and 5 were not statistically significant within each different fertilizer treatment. At the low rate of addition of fertilizer from between 89 and 91 kg-N/ha was fixed in plant tissues. At the highest rate between 98 and 113 kg-N/ha was converted into plant shoots and roots. Leaching and runoff losses only accounted for between 6.3 and 9.0 kg-N/ha.

5. CONCLUSIONS

The results indicate that, provided moderate amounts of fertilizer are added, tailings sand slopes can be stabilized by the establishment of a plant cover. Soils that require revegetating in mined areas or other disturbed locations must be adequately characterized before costly programs are started. Poor chemical, physical and biological characteristics can often be improved by the use of local soils and overburdens.

TABLE 18. Summary of the fate of nitrogen.

	Fertilizer Added kg/ha	Plant kg/ha		Water Losses kg/ha		Eroded Soil kg/ha	Soil Mineral-N 0-30 cm kg/ha	
		Tops	Roots	Runoff	Leaching		June	Sept
Fertilizer rate A								
1. 15 cm peat	80	59	32	ND	1.7	ND	25	4
5. 5 cm overburden over peat	80	69	20	ND	2.0	ND	43	7
Fertilizer rate C								
1. 15 cm peat	300	76	22	0.4	4.9	1.0	74	61
5. 5 cm overburden over peat	300	88	25	2.6	5.2	1.2	43	60

The total nitrogen present in the surface 0-30 cm in June 1976 varied between 840 and 1860 kg-N/ha.

Further work should enable several important questions to be answered. Of immediate concern is the extent of continued fertilization needed before such areas can be considered self sustaining and essentially maintenance free. Of particular concern in potentially erodable areas mentioned here is the ability to increase root penetration below the surface amendment layers to increase physical stability of the area.

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PAPER

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OIL SAND TAILINGS
INTEGRATED PLANNING TO PROVIDE LONG-TERM STABILIZATION

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OIL SAND TAILINGS
INTEGRATED PLANNING TO PROVIDE LONG-TERM STABILIZATION

ABSTRACT

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Processing oil sand involves material handling on an unprecedented scale, and creates vast quantities of waste or tailings. Large retaining structures are constructed from the sand tailings and used to retain the finer-grained waste products.

Service demands of the retaining structure are reviewed along with a study of factors that affect the long-term stability.

The retaining structure must remain intact during construction and resist erosion until protective vegetation is established. Then it must support the fine-grained waste products until they consolidate and are able to stand by themselves. Finally, the retaining structure must erode at a controlled rate that avoids release of large quantities of sand into the surrounding area.

Present construction methods appear adequate for short-term stability considerations, but the support will be required for 1000 years or more until fine-grained wastes consolidate and are able to stand by themselves. Eventually, the tailings retaining structure will succumb to natural erosion by running water and wind. Because of the concentration of fine sand in the retaining structure, erosion, once started, is likely to be quite rapid. Consequently, it is doubtful if the present structures will be able to meet long-term stability requirements.

Methods of reducing the rate of erosion and of reducing the required support time are explored. The key lies in planning that integrates long-term needs, operational considerations, and reclamation requirements.

Alternate construction methods that are more likely to meet long-term stability requirements are identified. The main considerations include accelerated consolidation of the fines, controlling surface runoff even while the overall structure is eroding, and introducing barriers to prevent rapid erosion of the sand. Adoption of these construction methods would enhance overall performance. Operating costs may be reduced because of the increased storage capacity that results from accelerated consolidation of the tailings fines.

OIL SAND TAILINGS
INTEGRATED PLANNING TO PROVIDE LONG-TERM STABILIZATION

D.W. Devenny, P.Geol., P.Eng.

1. INTRODUCTION

Processing bituminous sand from open pit mining operations involves handling volumes of ore and creates volumes of waste that are without precedent.

Individual plants now under design or construction will produce one quarter million tons of waste per day. The waste will be stored in tailings ponds that rise 100 feet or more above the original ground surface, and 300 feet or more above the mine floor. Eventually, 20 to 30 square miles of tailings ponds will be created at each mine site.

Design guidelines exist for the design of conventional tailings structures (1) (2). These have been applied to oil sand waste handling. Complications arise, however, from the immense size of the operation.

The paper which follows outlines the goals of waste handling. Then it identifies problems peculiar to oil sand waste handling and processes that affect stability of the waste deposit. Methods of slowing erosion and stabilizing storage facilities are explored.

2. BACKGROUND

To produce each barrel of synthetic crude oil, one cubic yard of oil sand must be mined and processed, and more than two cubic yards of sand, clay and water disposed of.

Waste products are usually pumped to a nearby disposal area. In warm weather sand is extracted from the waste effluent and used to construct retaining dykes. The remaining clay-water suspension is discharged into the central tailings pond. In winter weather, dyke construction is not feasible so all waste products are discharged into the tailings pond without separation.

In its natural state, oil sand contains 10% clay and 90% sand. The volume doubles during processing, and because of an affinity of clay for water, the clay occupies 45% of the waste volume.

To accomodate the increase in volume between oil sand in situ and in waste, the tailings structure will rise well above the original surface of mined out areas. Typical cross sections of tailings ponds are shown in Figure 1.

Rehabilitation plans for the waste areas vary. Typical plans submitted to licensing bodies involve stabilizing the sand dyke and pond surface with protective vegetation. To stabilize the pond surface, weak near-surface materials are removed and the cavity backfilled before revegetation is attempted.

3. GOALS OF WASTE HANDLING

The overall goal of waste handling is to optimize the process so it can be handled with a minimum of effort and leave the waste in an environmentally acceptable state.

Components of the waste handling team are shown on Figure 2. Dependency on the overall goals is apparent.

The purpose of the retaining dyke is to hold or retain material in the central pond as long as it requires external support.

4. SOME UNUSUAL ASPECTS OF OIL SAND TAILINGS

4.1 Effect of Size

Conventional tailings structures are relatively small in comparison with their surroundings. As a result the consequence of failure is an accepted risk.

In comparison, oil sand tailings are so vast that they dominate the landscape. Failure that permits sudden release of material from the dykes would choke the surrounding area with highly erodible sand. Failure that permits release of the tailings fines would have a more severe, far-reaching effect down the adjacent waterway. It is doubtful if the normal risk would be acceptable for these types of failure.

All earth structures will ultimately erode and the material contained in them released to the surrounding terrain. In view of the large quantities of material present in oil sand tailings, and the potential for its release to dominate the surrounding area, consideration must be given to controlling long-term erosion of the facility.

4.2 Perpetuation of the Central Pond

Clay in the tailings pond slowly drops out of suspension and accumulates on the floor of the pond. The sedimented material loads previously sedimented material and causes it to compress and develop strength that is proportional to the effective overburden stress. The amount of potential settlement is large. Figure 3 shows that settlement in excess of 50% of the initial height of tailings fines can be expected in normal oil sand tailings ponds. The space created can be used to increase storage capacity of the tailings pond if settlement occurs while operations are ongoing. If it occurs later, the ground surface will settle and keep a permanent lake on surface.

The rate of consolidation of fine materials is governed by material properties, by site geometry (length of the drainage path through consolidating material), and by consolidation theory (3). Predicted time for consolidation of oil sand fines is shown in Figure 4. With a short drainage path, consolidation can be accomplished in a few years, while operations are still underway. With a long drainage path, however, consolidation will probably take thousands of years. Present methods of handling oil sand waste create very long drainage paths (150 feet +) so the consolidation precess will be very slow.

From the above considerations, we can expect fines in today's oil sand waste facilities to consolidate very slowly. As consolidation takes place the ground surface will settle and perpetuate a lake at surface.

4.3 Required Life of the Retaining Structure

The tailings dyke must support the interior tailings fines until they consolidate and develop sufficient strength that they can support themselves without external support. With present methods of oil sand tailings construction, it will probably be thousands of years before the fines stabilize. The retaining dykes must remain functional for that length of time!

Designing retaining structures made of highly erodible fine sand that must remain operational for as long as the pyramids have been in existence is something new. Existing design guidelines for tailings are based on relatively short term soil mechanics considerations. Evaluation of long term stability requires a review of geological erosion processes and an assessment of how they could affect retaining structures.

5. EROSION PROCESSES AND STABILITY

5.1 Short Term Stability

Short term stability aspects are covered by designing in accordance with soil mechanics principles. Features include densifying sand in the dyke to give it increased strength, selecting an overall geometry that is known to be stable and controlling internal pore pressures to ensure that stability is maintained.

Liquifaction of the dyke is prevented by placing materials in a dense state that resists liquifaction. The interior fines are, of course, already in a liquid state.

Protection against surface erosion by wind and water is provided by surface vegetation.

5.2 Long Term Stability

Erosion processes that assume importance for the long term are natural geological processes that are active on the landscape today. The main processes are erosion by running water and by wind. These are described below.

5.2.1 Surface Runoff

The dykes are constructed of uniform fine sand that is easily eroded by running water. Erosion by runoff from normal precipitation falling on the dyke slopes can probably be resisted by surface vegetation. However if the vegetative cover is ever broken, runoff will be channelled and downcutting will be difficult to stop once started. Energy barriers and erosion control devices should be built into the slope to prevent downcutting.

5.2.2 Overflow from Surface Ponds

The surface of the tailings area represents a sizeable drainage basin. Lakes that form there contain a lot of stored energy that would cause rapid downcutting and breach the dyke if overflow ever occurred.

Design for long term stability should include steps to minimize the volume of water that can collect at the surface and that controls drainage from the upland area.

5.2.3 Toe Erosion

Design of retaining structures located near major rivers must consider the long term potential for erosion at the edge of the river. Where extremely long term protection is needed, it would probably be advisable to locate retaining structures well back from the river. Alternatively, heavy rip rap and long term maintenance programs will be required.

5.2.4 Wind Erosion

Wind is an effective eroding agent of exposed uniform dry sand. Active sand dune areas north of Fort McMurray cover several square miles and demonstrate the potential for wind erosion. There, large sand dunes are migrating over and destroying protective vegetation - a process that is very difficult to stop once it is started.

Normal surface vegetation will prevent wind erosion, but active erosion can be expected to start at any break in the vegetative cover. Growth of the eroding area is a legitimate concern. Channels cut by running water are ideal locations for wind erosion to start. Consideration should be given to including strips of cohesive soil in the dyke profile to halt wind erosion.

Dust bowl conditions are common on the abandoned surface of tailings dams. Protective vegetative cover will be needed to prevent this from happening on upland areas.

6. CONSIDERATIONS FOR BUILT-IN STABILITY

6.1 <u>Location</u>

One of the first considerations affecting the overall vulnerability and stability of a tailings facility is its location.

Locations adjacent to major rivers are less desirable because:

(1) there is a higher environmental risk from a structure located immediately adjacent to a major river,

(2) erosion processes are more active in major river valleys, so more consideration will have to be given to resisting erosive forces there, and

(3) local relief - and hence energy from runoff water - is greater for structures near major river channels than it is for those "buried" in mined out upland areas.

6.2 Outlet for the Tailings Drainage Basin

An outlet channel should be provided so drainage from the tailings pond area can be directed away from the dykes and controlled discharge can occur. Large settlements that might take place from post construction consolidation should be taken into account when planning this facility.

The most appropriate outlet would be over an inland course that has a long section with a gentle gradient over stable ground.

6.3 Minimize Volume of Water in Waste Pond Areas

As noted earlier, ponds in the upland area contain considerable stored energy that can cut through the retaining dyke if flow ever occurs in that direction. For this reason long-term planning should include methods of eliminating upland lakes. Methods are indicated in Section 6.7.

6.4 Vegetative Cover

Thick vegetative cover is needed to protect the surface from erosive forces.

Sandy dyke soils tend to be well drained, so are not likely to support vegetative cover of the type desired. Consideration should be given to providing fertile soil and water that will enhance vegetative growth. The next section indicates one method of accomplishing this.

6.5 Buffer Strips of Cohesive Soil

Present designs produce a dyke that is essentially all made of sand. Buried strips of cohesive soil illustrated in Figure 5 offer a number of advantages that could justify the cost of providing them. Advantages include:

(1) cohesive layers would check downcutting by flowing water on surface,

(2) cohesive layers would check wind erosion,

(3) cohesive strips are apt to induce a perched water table that will support better surface vegetation, and

(4) cohesive soil that contains a variety of minerals is more likely to support dense vegetation than quartz tailings sand.

This design feature would not be necessary in structures that only have to cope with short term conditions. It is worth considering however, where long term service is needed.

6.6 Energy Barriers

Surface erosion channels are difficult to halt once started. Built-in energy barriers such as periodic rows of rip rap can prevent channels from developing over the full height of the dyke slope. Energy barriers of this type provide a natural method of maintaining the slope.

6.7 Accelerated Consolidation of Tailings Fines

Methods of accelerating consolidation of tailings fines have been reported elsewhere (4). With minor changes to operations during placement of the tailings waste, it appears feasible to accelerate consolidation so it will be complete in a few years, instead of taking thousands of years. Advantages of this include:

(1) the ground will be stabilized within an identifiable control period,

(2) up to 50% increase in storage capacity for tailings fines will result,

(3) tailings fines will develop strength and become self-supporting at the same rate as consolidation occurs. This will reduce the service requirement for the tailings dyke from long term (thousands of years) to a life span that is much more predictable, and

(4) when consolidation is complete surface settlement will stop. If this occurs early enough, it will be possible to reduce and perhaps even eliminate surface lakes.

Increased storage capacity, increased stability, and shorter life requirements for the retaining dykes are obvious advantages arising from accelerated consolidation.

7. CLOSURE

Waste facilities resulting from oil sand processing dwarf previous waste facilities. Peculiar problems arise from the size of the installations.

A review of the way in which materials behave in oil sand tailings facilities indicates that materials will not stabilize for a very long time - perhaps thousands of years. Retaining structures will have to provide support for that period of time.

Existing guidelines for the design and construction of tailings structures are based on short term considerations only. There is no precedent for such long term support. To assess factors influencing long term stability natural geological erosion processes have to be taken into account. Major processes influencing highly erodible oil sand tailings facilities include:

- erosion from surface runoff
- overflow from surface ponds
- wind erosion, and
- toe erosion by rivers and streams.

Consideration of the effect of natural erosion processes reveals stabilizing steps that can be integrated into tailings planning and construction. Major factors are discussed in the preceeding report. Considerations include:

(1) location,
(2) providing an outlet for the surface drainage basin,
(3) minimizing the volume of water in upland areas,
(4) providing dense vegetative cover,
(5) incorporating buffer strips of cohesive soil in the dyke,
(6) providing surface energy barriers, and
(7) accelerating consolidation of the tailings fines.

Many of the above factors are not required in tailings facilities that will only have a short life. However, they offer definite advantages to facilities that will be required to last a long time. Accelerating consolidation appears particularly advantageous and may reduce present operating costs.

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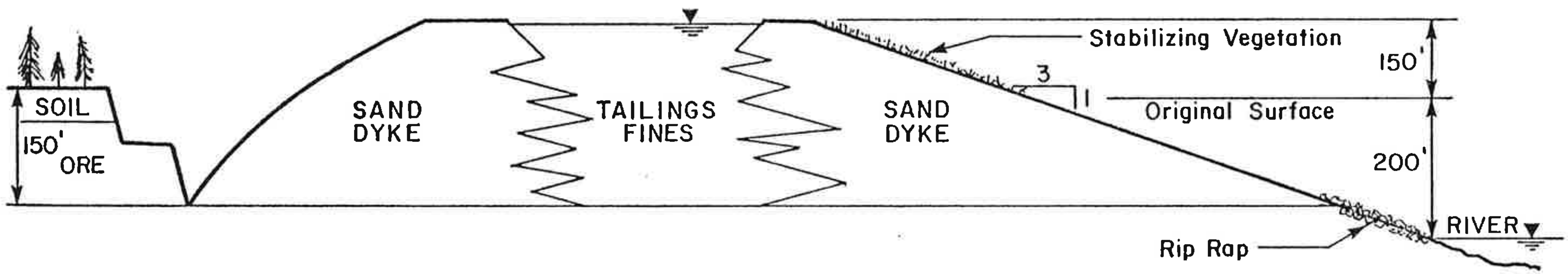

FIGURE 1 . CROSS SECTION OF A TAILINGS STORAGE DAM

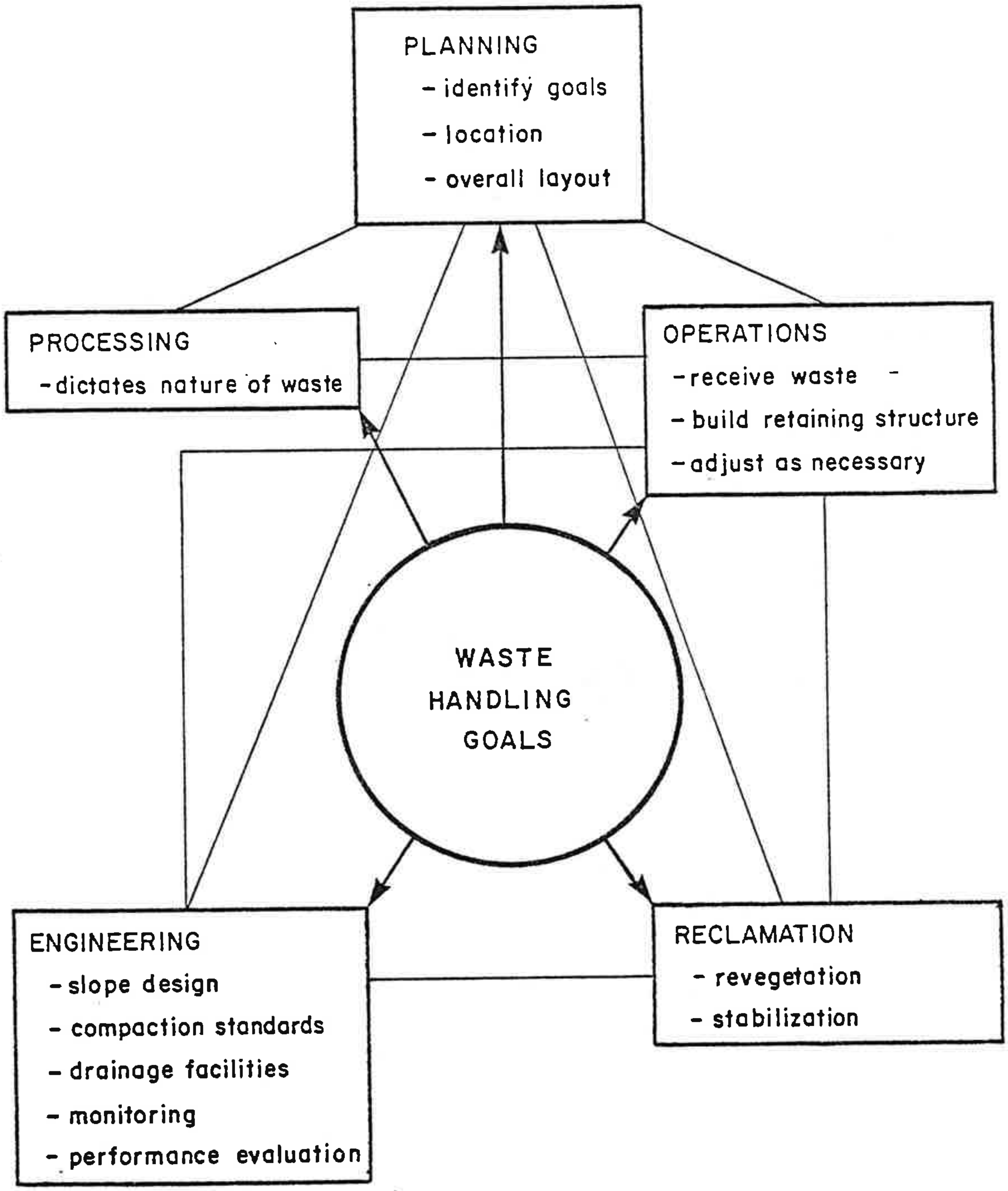

FIGURE 2 DISCIPLINES INVOLVED IN WASTE HANDLING SHOWING INTERDEPENDENCE AND CONTROL FROM OVERALL GOALS

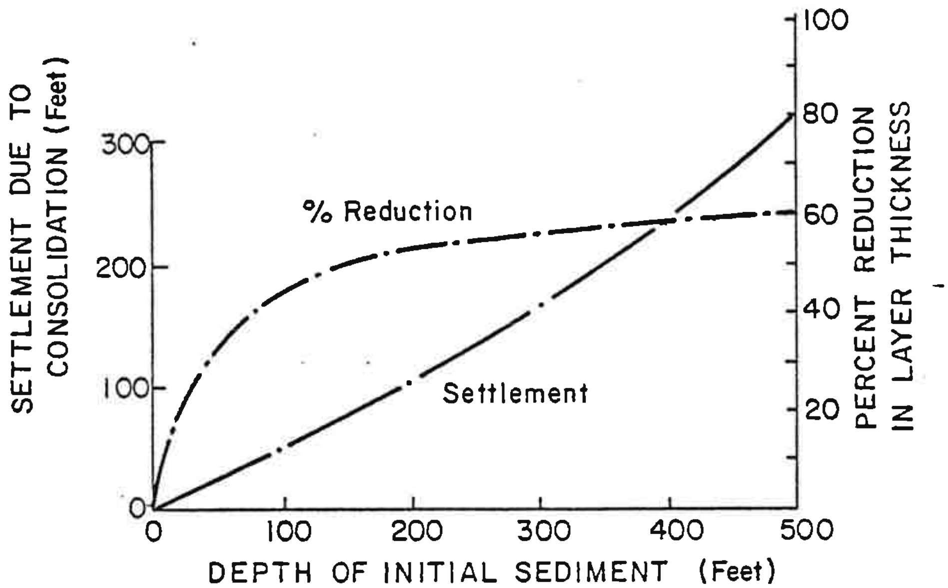

FIGURE 3 PREDICTED SETTLEMENT DUE TO CONSOLIDATION OF TAILINGS FINES

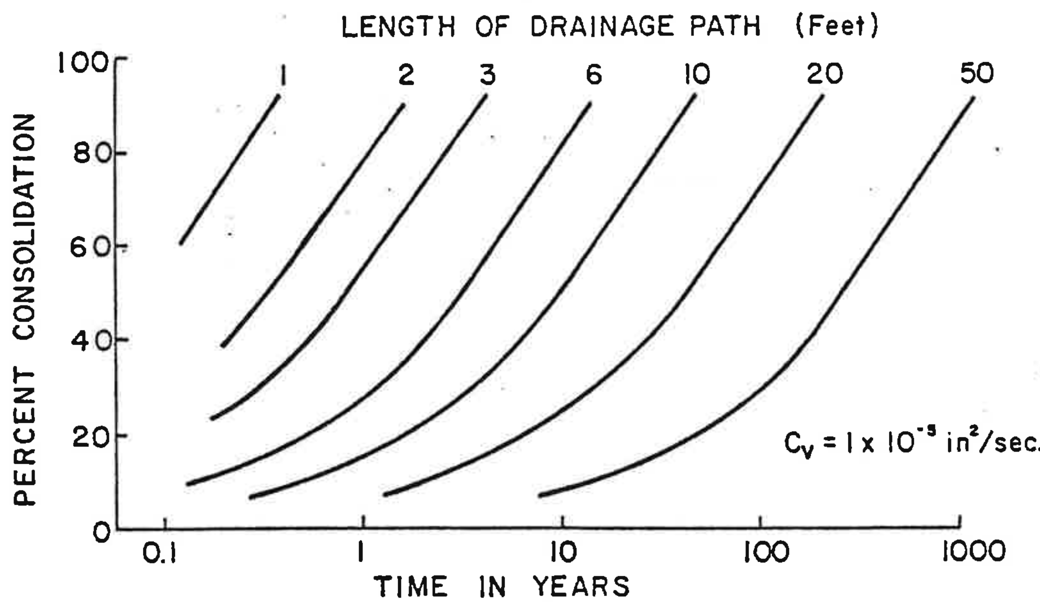

FIGURE 4 TIME RATE OF CONSOLIDATION FOR VARIOUS LENGTHS OF DRAINAGE PATH

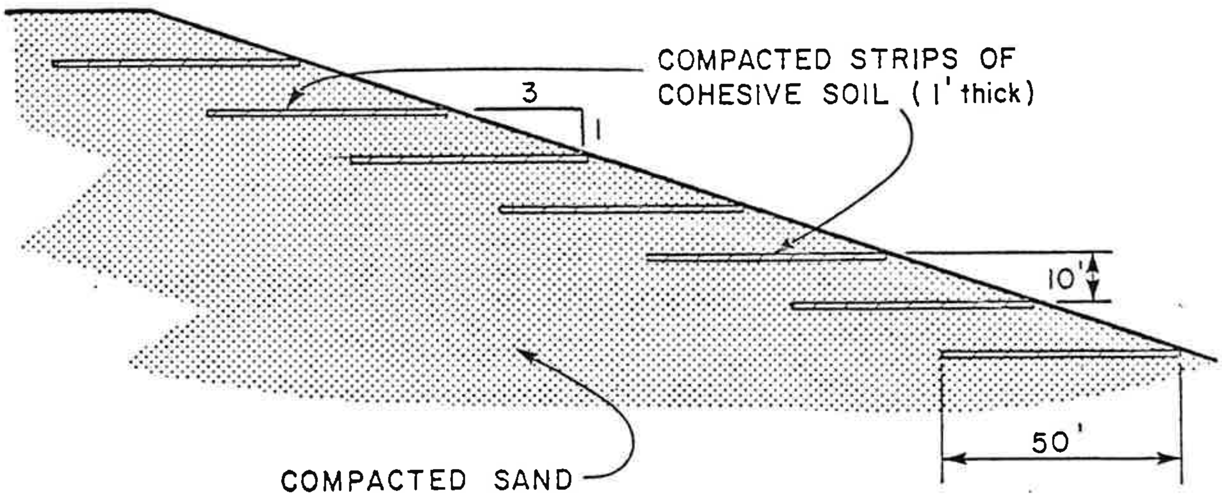

FIGURE 5 COHESIVE STRIPS IN SAND TAILINGS DYKE

PAPER

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BIOENGINEERING: THE USE OF PLANT BIOMASS TO STABILIZE AND RECLAIM HIGHLY DISTURBED SITES.

The bioengineering concept of reclamation developed in Europe is now becoming well established internationally with successful projects in Japan, Korea, New Zealand, Rhodesia, South Africa, Venezuela and the North American Continent. It is proposed as an alternative to conventional reclamation methods, particularily where conventional methods are producing less than desirable results.

I. Doubtless the plant cover is the most important protection layer for the soil surface and for the upper soil layers. It is, therefore, only logical to use live plants when a restoration of disturbed conditions in the landscape becomes necessary.

A program maintaining this idea was developed in the 1930's and originally called LIVE CONSTRUCTION. Today we are in a position to offer a series of so-called BIOENGINEERING BUILDING SYSTEMS, which have all been tested and proved successful under the most diverse conditions.

A bioengineering building system is the application of live plants or plant material either exclusively or in combination with dead material.

Basically these systems serve the stabilization of certain terrain sections and the improvement of ecological conditions in utilizing natural materials available at the building site. We thereby are provided with a means to preserve and protect something already established as well as repair damage by establishing new eco-systems in those areas devoid of vegetation.

In order to be able to apply bioengineering methods it is essential to know the building material - i.e. the suitable plants. Their propagation (especially vegetation propagation), their requirements of the locality, their bio-technical qualifications (i.e. resistance to burying, to erosion, their root development and root hardiness, the soil penetration, their regeneration ability after ...

damage etc.) must be known as well as their position in the natural plant succession - the pioneer phase, medium phase and final phase or climax community. Beside all that a sound knowledge of technical engineering is necessary.

II. WHERE LIES THE DIFFERENCE BETWEEN A BIOENGINEER AND CONVENTIONAL RECLAMATION WORK

The conventional approach to reclamation work usually utilizes specialist disciplines such as; forestry, agriculture, soil mechanics, biology, engineering, architecture etc., whereas the bioengineer receives a more comprehensive and more diversified training. He looks at a problem in reclamation work from the forester's, the agriculturist's, the biologist's, the landscape architect's, the soil specialist's, and the engineer's point of view all at once and considers all factors involved in reclamation work, such as; soil conditions, climatic conditions, characteristics and suitability of individual plants, technical, engineering and aesthetic aspects, specific problems of a certain locality, like altitude, slopes, water conditions, plant cover etc.
Professor Schiechtl, for example, is a civil engineer, a botanist and a landscape architect. He has been and is now being consulted by 17 different countries, including Libya, where at the moment the largest revegetation program in the world has been carried out for the last five years.
Reclamation personnel all over the world often try to "invent" systems already well known and established in bioengineering. To most problems the solutions have already been found and all one should do is to try to improve these established systems instead of re-inventing.
Bioengineering systems have long been standardized in German and Austrian construction codes and we strongly recommend a translation of these construction standards. Most common mistakes seen through past experience in reclamation work are:

1. Seeds and plants chosen were not suitable for their specific requirements; they had rather been picked according to availability, familiarity and costs. In many cases not enough plant varieties were used.
   Another point very rarely considered was the root production and the tensile root strength.
2. Plantings were carried out in blocks or rows instead of mixed random planting, which would have promoted a diversified root development and the development of a very resistant vegetation cover, which survives even if diseases, insects or fungi destroy some of the varieties. Nothing is worse than monoculture and block planting where suddenly a whole group of plants can vanish, apart from that it does not add to the aesthetic value of the area.
   An example of what may happen was seen in Kentucky where whole blocks of container planted pines were blown over by winds after approximately <u>twenty</u> years of planting. See in comparison Korean steep highway banks which were stabilized through the application of concrete gratings seeded with grass and random planting with a great variety of shrubs and trees. After twelve years a healthy, well-balanced vegetation cover was established.
   Another example of how planting should not be done is a slide area revegetated with pines, monoculture, straight rows in vertical direction instead of mixed planting and random spacing. This planting could be completely destroyed at any one time.

III. MOST IMPORTANT BIOENGINEERING BUILDING SYSTEMS

We differentiate between

1. COMBINED BUILDING SYSTEMS

   where hard construction (used in conventional technical engineering or reclamation work) are combined with live building materials. Their purpose is the stabilization and drainage of slope sections and the securing of erosion gullies to prevent further erosion). In Hydro construction, they serve as shore protection (Bank and SLOPE STABILIZATION and PROTECTION SYSTEMS along WATERWAYS).

The most important of these Combined Systems are KRAINERWALLS, made from timber or prefabricated concrete parts that are vegetated with live branches of some woody varieties such as; VEGETATED GABIONS, LIVE SLOPE GRATINGS, VEGETATED PALISADE AND POLE CONSTRUCTION, BRANCH LAYERING OF GULLIES, LIVE FASCINE DRAINS, LIVE STAKE DRAINS, LIVE KUENETTE (open water channel), and LIVE DRAIN WEDGE.

In Hydro contruction, mainly LIVE BRUSHES, REED PLANTINGS with root stocks, rhizomes and sprigs, WATTLES, FASCINES, SPREITLAGEN, ROCKFILLS WITH BRANCH LAYERING, BUSCHBAUTRAVERSE (LIVE SILTATION CONSTRUCTION), GITTERBUSCHBAUWERK (an arrangement of pegs or pilots and branches or trees), and BRANCH PACKINGS are used.

2. STABILIZING CONSTRUCTIONS

   Their purpose is a deep-reaching soil stabilization and compaction and the consolidation of loose material. The most effective and today most commonly used stabilization constructions are the LAYER CONSTRUCTIONS (HEDGE LAYER, BRUSHLAYER AND HEDGE-BRUSH LAYER CONSTRUCTION), the various methods of PLANTING OF CUTTINGS, WATTLE FENCES and SLOPE FASCINES.

3. SURFACE PROTECTION CONSTRUCTIONS

   They serve the protection of the soil surface from erosion and damage through tensile and compressive forces caused by heavy rain, hail and wind. The most commonly used ones are TURF AND LAWN SEEDINGS, and SPREITLAGEN CONSTRUCTION, which protects the soil surface through the placement of a layer of live branch as well as all SODDING SYSTEMS.

4. SUPPLEMENTARY BUILDING SYSTEMS

Their purpose is the improvement and stabilization of the established initial vegetation and the promotion of its further natural development into the climax vegetation. The most important methods are SEEDING OF WOODY PLANTS and the various PLANTING and AFFORESTATION SYSTEMS.

IV. APPLICATION FIELDS AND EFFECTS OF BIOENGINEERING METHODS

Bioengineering building systems can be applied both in hydro construction and earth work. Their immediate application has in fact, prevented permanent damage on a huge scale that would have resulted from most construction projects. The use of bioengineering systems is justified if one of the functions that are listed in the chart below has to be fulfilled. Their application is absolutely necessary if these requirements can not be sufficiently fulfilled by hard construction.

Requirements for the effect of bioengineering building systems

Earth Work	Hydro Construction
Technical Effects	
Protection against wind-, rain-, and frost erosion	
Protection of the soil surface against wind-, rain-, and frost erosion	and erosion by flowing water
Protection against rock fall	
Protection of the soil surface against damage from heavy rain and hail	and drifting ice
Elimination or control of damaging mechanical forces, thereby prevention of e.g. minor slides	
surficial or deep-reaching soil stabilization and compaction thereby e.g. raising of the possible slope inclination angle	
Protection against blinding and thereby optical channelling effect traffic	reduction of current in the shore area
	reducement of the waves
drainage	water purification (cleansing)
increase of roughness of soil and thereby prevention of avalanches	
promoting the snow deposit, incl. avalanches and moving material (only possible with woody plants)	
Wind protection	

Economical Effects

- Reduction of construction costs compared to hard construction (conventional engineering construction)
- Reduction of costs for maintenance and for repair and restoration
- Providing usable green areas and forest communities with vegetation on previously barren land.

Ecological Effects

Improvement of water conditions through higher interception of the water-retention capacity of the soil and of water consumption through transpiration

Drainage of Soil

Wind protection

Immission protection

loosening and stabilization of the soil through penetrating plant roots

Stabilizing the temperature conditions in the soil and in the air layers near the soil

Shading

Improvement of nutrient content of soil through decaying plant parts, through symbiosis and Allelo-parasitism; thereby inducing biological cycles, creation of an animated top (surface) soil layer, activation of the soil fauna and flora and thus increase of soil fertility in previously raw mineral soils.

Control of snow deposit

improvement of spawning places

Increase of production in re-shaped areas behind wind protection systems

Landscape - Architectural (Aesthetic) Effects

- Reduction of construction costs compared to hard construction (conventional engineering construction).
- Reduction of costs for maintenance and for repair and restoration.
- Providing usable green areas and forest communities with vegetation on previously barren land.

Bioengineering systems have numerous advantages compared to conservative engineering systems applied in reclamation work (also called Hard Constructions) Certain technical functions such as; erosion control, protection of the soil surface against heavy rain and hail, deep-reaching soil stabilization and consolidation, reduction of current and waves etc., can not be fulfilled as effectively by any of the Hard Constructions as with bioengineering methods. This goes to an even greater extent for ecological functions, and for aesthetic and economic effects.

V. MAINTENANCE

From past experience we can prove that the preservation and maintenance of bioengineering systems is in comparison to hard constructions, simple and economical. If the appropriate plant varieties and bioengineering methods have been chosen, little maintenance is necessary. Through the natural plant succession the established initial vegetation should develop into the climax community by itself.
At extreme unfavourable localities this development can be promoted and accelerated through the application of SUPPLEMENTARY BUILDING SYSTEMS with some fertilization, mowing, and pruning of woody plants etc.

VI. VARIOUS EXAMPLES OF BIOENGINEERING SYSTEMS AND THEIR PRACTICAL APPLICATION.

Pictures and diagrams shown.
The examples presented show approximately 1% of the total amount of bioengineeri systems known and applied today. We hope that it will give you some impression of what we are trying to explain and that you were able to get the main idea of what bioengineering systems are all about.

We would also like to point out quite clearly that we are not fully qualified bioengineers though we have been using some basic systems. We have been convinced of their great importance in the field of reclamation work and their immense value to anyone concerned about his/her environment.

VII. WHERE CAN WE LEARN THE MOST ABOUT CERTAIN SPECIFIC PROBLEMS IN RECLAMATION WORK?

1. Steep slopes - Austria, Switzerland, Italy, Korea, Japan.
2. Toxic material - Rhodesia, S.Africa, Germany, Austria, France.
3. Sand - Holland, N.Germany, France, US Pacific and US Atlantic coast, State of Washington, Tunisia, S.Africa, Israel, S.W.Africa, Southern France.
4. Salt - Holland, N.Germany, Tunisia, S.Africa, Japan, Israel.
5. High Altitude and Arctic Climates - European Alps, Norway, Sweden, Alaska.
6. Wind problems - S.Africa, Tunisia, Israel, Southern France, Iran.
7. Water - European Alps, Holland, N.Germany, and the leading water institutes in Germany.
8. Ski runs and avalanch control - Austrian, Swiss and German Alps.

The most important reclamation projects that we have seen or are aware of are in our opinion Mr. Perry Plummer's work in Utah, the late Mr. Kraeble's work in California, Mr. Hill's work in Rhodesian copper mines, and in Europe various projects by Professor Schiechtl and others.

Other projects of interest are the Brown coal mines in Germany and the largest current reclamation project of its' kind in the world now in its' fifth year in Libya under the auspicious Khadify regime.

The most extensive records available on a reclamation project are in Grenoble, S.E. France, where a whole district was declared a disaster area approximately 250 years ago and where the mountains have been gradually revegetated during this period.

We are grateful to the organizers of this conference for providing us with the opportunity of presenting this material.
It is our belief, based on our own experience, that the potential for the bioengineering concept of reclamation has not yet been realized here, and we firmly believe that many applications exist where better results could be achieved, both from the stand point of economics and long term solutions.

Thank you

PAPER

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RECLAMATION OF COAL REFUSE MATERIAL ON AN ABANDONED MINE SITE AT STAUNTON, ILLINOIS*

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ABSTRACT

In the State of Illinois lands that have been abandoned after deep mining or strip mining of coal present unique land reclamation problems. One such area is the Staunton 1 Reclamation Site. Through the efforts of three agencies -- the Illinois Institute of Environmental Quality, the Illinois Abandoned Mined Land Reclamation Council and the U.S. Energy Research and Development Administration -- this 13.8 ha (34 ac) site has been transformed from an eyesore that dumped acidic runoff into the nearby watershed to a demonstration area where reclamation research is now taking place. Ultimately, the site will be a wildlife and recreation area.

The old Consolidated Mine No. 14 was located in Macoupin County, northwest of the town of Staunton, Illinois. The refuse at this mine site was creating environmental problems that are typical of refuse areas in Illinois. Among these problems are runoff pH values of 2.6; severe erosion gullies; slopes of 1:1, 1:2, and steeper; gob and slurry with pH of 2.2; poor water quality; and sedimentation of tributaries of the Cahokia Creek watershed. The area was used as a dumping ground for various junk items such as stoves, refrigerators and metal cans. Overall the site had no productive value. Preliminary observations at the Staunton 1 site indicated that extreme environmental degradation had been

*This project was funded by the following agencies: Abandoned Mined Land Reclamation Council, State of Illinois Contract No. 31-109-38-3694L; Illinois Institute for Environmental Quality, Contract No. 31-109-38-3694L; U.S. Energy Research and Development Administration, Contract No. 31-109-Eng-38.

caused by various physical and chemical characteristics of the refuse material. High concentrations of available boron, zinc, sulfate, and soluble salts; low concentrations of available nitrogen and potassium; and lack of organic matter make the refuse very poor soil for vegetative growth. In addition to these chemical characteristics, the physical properties of the refuse materials inhibited plant growth and encouraged erosion.

Sediment from this pile has silted an area of about 4 ha (10 ac) immediately surrounding the pile. An earthern dam was constructed for the impoundment of water for the mining operation and allowed the coal fines and silt to settle out. Culverts at the top of the dam allowed excess water to drain from the impoundment, thus leaving the sediment to accumulate. This earthern dam was breached by erosion after the mine closed in 1923, and subsequent erosion carved deep gullies in the exposed stratified sediment. Drainage from the refuse pile flowed north through the old impoundment area and continued north-northwest where it entered Cahokia Creek.

The entire area was recontoured during the construction. All slopes were reduced to 5:1 or less. A 0.5 ha (1.2 ac) retention pond was constructed to help control runoff. Agricultural limestone was applied at a rate of 220 t/ha (98 tons/ac) on some areas. Other areas received Code L Alkali at a rate of 152 t/ha (68 tons/ac) to neutralize and stabilize the acid slurry material. The entire site was covered with 0.3 m (1 ft) of suitable cover material, limed, fertilized, and seeded.

This paper will trace the history of this land reclamation project from its early planning stages, through the construction phase, and up to the present research.

RECLAMATION OF COAL REFUSE MATERIAL ON AN ABANDONED MINE SITE AT STAUNTON, ILLINOIS

The extraction and processing of coal is generally accompanied by the problem of disposing of large volumes of waste materials. In 1962 the State of Illinois enacted its first reclamation law for coal mining. This legislation, with its subsequent amendments, requires that all lands disturbed by coal mining and processing be reclaimed. The legislation does not carry a "grandfather clause"; therefore approximately 46,900 ha (116,000 ac) of disturbed lands in the State of Illinois are not governed by this act. Current information[1] indicates deep coal mining operations in the State of Illinois have taken place at over 4,000 locations. Approximately 700 of these sites, covering about 2800 ha (7,000 ac of gob and slurry) are seriously affecting their surrounding environment. A second study[2] reveals over 44,100 ha (109,000 ac of spoil) of Illinois lands had been surface mined prior to 1962. Roughly 6900 ha (17,000 ac) of the total surface mined land also have serious environmental problems. Therefore, nearly 9,700 ha (24,000 ac), or over 20% of these lands affected by mining in Illinois, are creating environmental problems. These abandoned lands are owned by various agencies, coal companies, private concerns, municipalities, and by the State of Illinois.

The problems posed by abandoned coal mining sites are basically non-productive use of the land, loss of aesthetic value, and the production of pollutants with their dissemination into the surrounding environments. Before it is mined the coal and associated waste material is in equilibrium with its environment. When the refuse is deposited on the land surface, an equilibrium must be reestablished with the new environment. The production of acid material, acid runoff water and sediment are all symptoms of this readjustment. The natural processes which accomplish this readjustment are very slow. Conceivably, it could take hundreds of years to reclaim an abandoned coal mine site by natural processes and adversely affect the adjacent environment during the readjustment time.

These mined areas contain the waste from coal cleaning or surface mining operations. The waste deposited on the disturbed land contains coal, slate, rock, soil and pyrites. The four basic chemical equations that represent the acid production and the major environmental problems associated with coal mining are as follows:[3,4,5]

$$2FeS_2 + 2H_2O + 7\,O_2 = 4H^+ + 4SO_4^= + 2Fe^{++} \qquad (1)$$

$$4Fe^{++} + O_2 + 4H^+ = 4Fe^{+++} + 2H_2O \qquad (2)$$

$$Fe^{+++} + 3H_2O = Fe(OH)_3 \downarrow + 3H^+ \qquad (3)$$

$$FeS_2 + 14Fe^{+++} + 8H_2O = 15Fe^{++} + 2SO_4^= + 16H^+ \qquad (4)$$

In Equation 1 the sulfide in the pyrite is oxidized by the oxygen, and forms sulfate. If this equation happends in a soil, "cat clays" or acid sulfate soils, are formed.[3] In Equation 2 the ferrous ion is changed to ferric ion. In Equation 3 the ferric ion is hydrolized to form ferric hydroxide -- a powdery whitish-yellow insoluble precipitate commonly called "yellowboy." Equation 4 represents the reduction of the ferric ion by pyrite to form the ferrous ion. This equation represents the complete cycle since the ferrous ion needed in Eq. 2 is made available by the reaction in Eq. 4.

Examination of these equations indicates that runoff occurring on any site with pyrite available for oxidation would have very low pH values. Unless the vegetation is very acid tolerant, plant growth would suffer or be nonexistent under these conditions. Since steep slopes are usually associated with spoil areas and gob piles, with little or no vegetation to slow down the runoff, severe erosion problems can result. The coal cleaning procedure generates slurry areas where the liquid refuse from the coal washing process has been discarded. The acidic nature and fine texture on slurry areas also creates potential erosion problems. The low water quality values and sedimentation problems resulting from severe erosion can seriously affect the entire watershed. Problems such as these are common to lands disturbed by coal mining and processing.

Large refuse piles, without vegetative cover and with steep-sloped sides that are deeply eroded, are generally unappealing to the eye. In many cases, these refuse areas have become general dumping grounds for discarded material of all types. Sizable spoil areas, with sparse vegetative cover and alternative ridges and valleys of overburden, are a blot on the landscape.

These abandoned lands, in their present condition, have no specific land use or potential economic value. These factors, when coupled with the aesthetic and environmental status of the sites, have a tendency to create a depressed economic market for adjacent properties.

The primary goals of all reclamation projects are to: (1) reduce the quantity of pollutants entering the environment from the site; (2) increase the economic potential of the area; and (3) improve the aesthetic quality of the locality. With these general goals in mind, two state agencies -- the Illinois Abandoned Mined Land Reclamation Council and the Illinois Institute of Environmental Quality -- and the U.S. Energy Research and Development Administration through the Land Reclamation Program at Argonne National Laboratory (ANL) developed a cooperative reclamation demonstration program. A fourth overall goal was established for the cooperative effort -- develop, demonstrate, and evaluate methods and technologies of reclaiming refuse areas to have the greatest benefit at the lowest cost. This program was initiated by the selection of the Staunton 1 Reclamation Demonstration Project as its first effort.

The program has been subdivided into the following phases:

Phase I	Planning and Design
Phase II	Baseline Monitoring
Phase III	Site Development
Phase IV	Post-development Monitoring

The first task in Phase I of the program was the selection of a typical refuse pile as a research site. The abandoned Consolidated Mine No. 14, located northwest of the City of Staunton in Macoupin County, was typical of coal refuse sites in southwestern Illinois. The mine was opened in 1904 and closed in 1923.

The waste materials from the operation were still very evident, in the form of an imposing gob pile. The refuse heap covered approximately 1.8 ha (4.5 ac), extended about 25 m (80 ft) above the natural landscape and had an estimated volume of 99,000 m^3 (130,000 yd^3). The pile was steep-sided, had no vegetative cover, and erosion had cut deep gullies into its sides. Vegetation in adjacent areas had been affected by the acid runoff water, and the water courses were filled with sediment. The original concrete smoke stack from the power plant at the mine was still standing, but most of the mine structures had been removed. The concrete foundations of some structures still remained and all the mine shafts had been filled. The railroad track which serviced the mine had been removed, but the right-of-way was still very evident along the southwest boundary of the property. The site was littered with large amounts of waste building materials, discarded household goods, many tin cans, and broken glass. From outward appearances, the site had been used as a general dump for a number of years. Acid runoff drainage was prevalent on the site. The drainage was to the north into Cahokia Creek, about one half mile north of the site. The drainage was filled with acid materials that had eroded from the gob pile and slurry resulting from the coal washing operation at the site. The depth of this material reached a maximum of 9 m (30 ft) in the old slurry pond which was at the north end of the site. The dam, which created the slurry pond, was breached about 35 years ago, resulting in erosion gullies to a depth of 4.5 m (15 ft). The acid nature of this slurry material had prevented the development of any vegetative cover on this 4.5 ha (11 ac) area of the site. The vegetation on the remainder of the site consisted of volunteer herbaceous shrubs, grasses, and trees. There was also evidence of small game in the area. The total site included approximately 13.8 ha (34 ac), of which about 9.3 ha (23 ac) required reclamation.

The second task in this phase of the program was to determine the final land use of the site. Because the area is near a railroad, improved surface roads, and an area which had been developed by industry, a possible usage would have been an extension of the industrial development, which would have complemented the economic base of the City of Staunton. After a soil investigation of the site by an independent engineering firm, this final land use was determined to be impractical.[6]

Due to the nature of the material at the site and the need to control acid runoff from the refuse, any proposed land use was somewhat limited. Therefore, a vegetative cover had to be established and maintained to control erosion and runoff. Any future development which would disturb the protective vegetative cover must be discouraged. After consulting local officials, and the West-Central Illinois Valley Regional Planning Commission, and taking into account the physical properties and chemical characteristics of the site, it was determined that the area was to be developed as a recreational area, wildlife habitat, and ecological educational area. Future overall land use and type of recreation activities must be limited to maintain the stability of the area.

With these final land uses in mind, detailed engineering plans and specifications were developed. Generally, the reclamation plan included: recontouring of refuse materials, disposal of man-made structures, improvement of the water courses, development of a pond, and reconstruction of the old dam with water flow control structures. Following the recontouring of the refuse materials, agricultural limestone would be applied to neutralize the refuse material, as would 0.3 m (1 ft) depth of suitable cover material. Preparation of a seedbed would include liming, fertilizing, and seeding with a mixture of grasses and legumes.

Phase II, Baseline Monitoring, was instituted to assess the pre-development environmental conditions of the study area. A number of groundwater observation wells were installed to establish and determine the groundwater quality of the site. Of the many samples collected, three groups of water quality were observed. Groundwater in the glacial till underlying and adjacent to the refuse pile had low pH, high concentrations of sulfate, alkaline earths, and heavy metals. These leachate constituents were not found in groundwater samples collected from wells at distances greater than 91 m (300 ft) from the refuse pile. Groundwater samples collected from wells in the saturated slurry material also had low pH, high concentrations of sulfate, alkaline earths, and heavy metals. Samples from residential wells of the area were found to contain primarily calcium, magnesium, carbonates and sulfates, but appeared to be unaffected by the refuse leachate. Table 1 shows typical groundwater quality data from one sample collection in June 1976.

Surface water collections were made at the site starting in the spring of 1976. In general, the pH of surface water was very low with high concentrations of sulfate, iron, zinc, and cadmium. Table 2 shows the analysis of four typical collections made at the site.

Table 1. Staunton 1 Groundwater Quality, June 1976

Parameter	Concentrations in PPM (except pH) From Slurry Material (4 Samples)	Near Refuse Pile (6 Samples)	Unaffected Areas (6 Samples)	Max. Recommended Drink. Water Limits[a]
pH	4.35-7.10	2.4-4.15	6.55-7.25	
total alkalinity	0-546	0	90.5 -185	
HCO_3^-	0-666	0	110 -226	500
$SO_4^=$	230-5174	1258-5739	66-1371	250
Acidity	47-2604	372- 8370	14.9-62	
Ca	239-456	470-569	44-387	200
Mg	45-220	30.5-84.3	13.1-194	125
Na	89-347	7.7-32.7	12.8-229	200
K	7.2-17	0.1-66	0.1-5.4	
Fe	6.35-1840	1.02-3940	<0.05-.14	1.0
Mn	0.43-41	4.9-51	<0.05-1.1	0.05
Al	<0.1-72	17.7-980	<0.1	
Cd	<0.02	0.11 -2.6	<0.02	0.01
Cr	<0.05	<0.05-1.42	<0.05	0.05
Cu	<0.02	0.02 -0.72	<0.02	1.0
Ni	<0.05-1.15	0.39- 2.81	<0.05	1.0
Zn	0.072-40.5	9.97-123	0.013-0.048	5.0
Sr	2.5-3.5	0.5-1.0	0.3-1.0	

[a]Recommended limits from McKee and Wolf[7] and Davis and DeWiest[8]

Table 2. Staunton 1 Surface Water Quality

Parameter Date	Concentrations in PPM (except pH) 4-15-76	5-13-76	10-15-76	10-22-76
pH	3.9	3.4	2.6	3.1
Acidity	3596	4092	6300	3825
$SO_4^=$	7095	9058	7000	4800
Al	498	607	527	143
Fe	1450	1510	1175	879
Mg	31	20	45	21
Zn	75	71	0.097	41
Cd	0.59	0.66	0.90	0.28
Cu	0.49	0.37	0.47	0.09

Surface materials, to a depth of 1.2 m (4 ft), were collected from three distinct areas --- slurry area, gob pile, and adjacent farm field. Routine soil analyses were made to determine the availability of various plant nutrients and the suitability of these materials for vegetation establishment and growth. Table 3 lists the average values for a group of samples collected in June of 1976. Soil pH in water from all three areas was extremely low. Generally, field soil samples were low in available plant nutrients. Both gob and slurry samples were high in soluble salts and had excessive amounts of boron and zinc which may have interfered with vegetative growth.

Table 3. Staunton 1 Surface Material Chemical Analysis, June 1976

Sample[a]	pH	Soluble Salts (mhos/cm x 10^{-5})	Parts Per Million							
			P	K	Ca	Mg	B	Mn	Zn	SO_4-S
Field	4.0	20+	36	156	383	100	1.8	44.8	8.1	214
Slurry	2.2	235	236	76	1870	100	35.5	5.6	53	3412
Gob	2.2	354	52	103	9758	1680	21.5	7.7	156	8733

[a]Sample averages

In addition, physical measurements were taken on surface material collected from the various areas of the site. Table 4 summarizes this information. The bulk density of both the gob and slurry material was low (< 1.00 kg/m^3). The general lack of large size particles (> 25 mm) may have been due to the method of mining and the coal cleaning process. This size distribution was probably not due to physical weathering, as the same general particle size distribution was observed throughout the gob pile and slurry area during the recontouring of refuse materials.

Other monitoring activities on the site included a sampling and analysis of surface materials for soil microbes. It was observed that the gob and slurry areas lacked any form of soil microbial life. However, soils from adjacent fields did have those forms of soil microbes normally found under cultivated agricultural conditions.

Table 4. Staunton 1 Surface Material Physical Analysis, June 1976

Sample[a]	Bulk Density (kg/m^3)	Largest Particle	% > 2 mm	< 2 mm Texture Class[b]
Field	1.33	12.5 mm	7.02	Silt Loam
Slurry	0.88	25 mm	22.34	Sandy Loam
Gob	0.93	22 mm	37.64	Loam

[a]Sample averages

[b]Glossary of Soil Science Terms[9]

A limited wildlife inventory was made of the site. It was determined that the areas not affected by the refuse material had wildlife populations normally found in the area, but those populations made little use of the refuse area itself.

Extensive growth chamber studies were conducted at the ANL facilities to investigate the effects of various types and levels of soil amendments, as well as vegetative species which could be used in reclaiming the site. Results from these studies[10,11,12] were used in determining species to be seeded on the site and soil amendment types and rates.

During the summer of 1976 detailed engineering plans and specifications for the construction phase of the program were completed. The resources of the Illinois Department of Transportation were utilized to obtain bids for the site development work. The State of Illinois acquired title to the property and the construction contract was awarded to Marle, Inc. of Springfield, Illinois, the low bidder, on September 15, 1976.

Phase III, Site Development, began with a general clean-up of the work area. This task included the removal of mine structural foundations, the smoke stack, and disposal of accumulated debris. An on-site borrow pit was opened and suitable cover material, removed from the pit, was stock-piled. By late October the gob pile was reduced to approximately 1/3 its original height. During the rough grading in the north area of the site, the contractor experienced problems in moving equipment over the saturated slurry material. Various attempts were made to dewater the area using drainage channels, pumping, and the substitution of Code-L Alkali for ground agricultural limestone. This material was selected because of its capability to neutralize and stabilize acidic, saturated materials. Due to difficulties encountered in the slurry area, the location of the pond was changed so that the base of the pond would be in till material rather than in saturated slurry material. As work progressed on the relocated pond, the Staunton area experienced its severest winter on record. Extremely cold weather and above normal amounts of snowfall slowed progress on the project. The construction of the dam, installation of the culvert pipe, excavation of the pond, and grading on the gob pile were all delayed by uncommon winter weather. General construction ground to a halt for two weeks in February of 1977.

Upon resumption of construction activities, as rough grading neared completion, the application of the neutralizing material at the refuse-material/suitable-cover-material interface began. The equivalent of 220 t/ha (98 tons/ac) of ground agricultural limestone was applied to the exposed refuse material. The neutralizing agent was incorporated to a minimum depth of 0.15 m (6 in.) into the refuse material. Suitable cover material was then placed over the regraded refuse material at a minimum depth of 0.3 m (1 ft).

By mid-April all grading had been completed and suitable cover material was in place. The seedbed was prepared with the application of 11.2 t/ha (5 tons/ac) of ground agricultural limestone and 135 kg/ha (120 lbs/ac) each of nitrogen, phosphorus, and potassium plant nutrients. These amendments were incorporated to a minimum depth of 0.1 m (4 in). The area was then drilled using an agricultural grain drill with the following seed mixture per acre: Reed canarygrass -- 4.5 kg (10 lbs); Kentucky 31 fescue -- 6.8 kg (15 lbs); Ladino Clover -- 2.3 kg (5 lbs); Birdsfoot Trefoil -- 5.4 kg (12 lbs); and cereal (Balboa) rye -- 9.1 kg (20 lbs). Seeding was completed the last week of April as was the fencing of the site perimeter. Final clean-up and minor hand work was completed on April 29, 1977, the day the construction contractor left the site.

During the month of April various research facilities and demonstration areas were prepared for the post-construction evaluation phase of the program. On May 25, 1977, the final inspection was made of the site development work by representatives of the funding agencies. This event was also attended by local and state officials, interested parties and various media personnel.

Phase IV, Post-construction Evaluation, began on April 30, 1977. The objectives of this phase are (1) to provide an overall assessment of the reclamation effort to determine its environmental effectiveness; (2) to develop, demonstrate, and evaluate needed technologies for future reclamation efforts; (3) to investigate and ameliorate potential environmental problems which may develop on the reclamation site; and (4) to provide the economic assessment necessary to transfer the most cost-effective reclamation techniques to future projects.

These objectives will be met with the establishment and maintenance of several interrelated demonstration projects. Each project will examine a specific portion of the reclamation effort, and the combination of information from each individual investigation will provide an overall assessment of the reclamation activity.

Groundwater hydrology and surface water quality are two studies being performed to determine what beneficial effects reclamation had on surface water quality and in Cahokia Creek. It will also provide a better understanding of the hydrological system of the reclaimed site. A study of the aquatic ecosystems will assess the effects of the reclamation effort on the macroinvertebrate communities of Cahokia Creek. This study will also determine the biotic colonization and succession patterns and rates within the on-site pond, and will develop a self-sustaining sport-fish community in the pond.

Another study will determine if site-wide revegetation efforts are successful and will establish limiting factors in site vegetation problem areas. An additional revegetation study will evaluate and field test several surface treatments, suitable cover material depths, and candidate plant species for the revegetation of reclaimed area.

A soil characteristic study will determine if significant changes occur over a period of time in the physical and chemical properties of root zone material at the site. This study will also look at whether available soil moisture or temperature are limiting factors in revegetation.

The relationship of slope angle and depth of suitable cover material to erosion rate and surface runoff water quality is also being examined.

Soil microbial population changes in relationship to site characteristics and reclamation practices are being determined by a soil microbial monitoring study. This study also relates microbial groups to a plant nutrient availability. Soil fauna establishment tests are being performed to determine survival rates and activity of soil fauna on limed refuse materials, mined and layered refuse material, and suitable cover material as related to soil fertility and structure. Another study being performed is a wildlife inventory which determines the species composition, use of the reclaimed area by wildlife and quality of the site as a wildlife habitat.

An additional investigation, which will provide an economic evaluation of the project, involves determining the cost-effectiveness of the various reclamation techniques being tested and the complete reclamation effort. The post-construction evaluation will continue for three to five years.

The primary goals of all reclamation projects are to reduce the quantity of pollutants entering the environment, increase the economic potential of the area and improve the aesthetic value of the landscape. An additional ultimate objective of the Staunton 1 Site Reclamation Demonstration Project is to develop and evaluate various methods of reclaiming refuse areas to have the greatest benefit at the lowest cost. Knowledge from this demonstration can be applied to the development of a systematic reclamation plan for abandoned refuse areas.

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PAPER

-12-

Paper No. 12

Author(s): S.E. Yundt

Title of Paper: "A Case Study of Materials and Techniques Used in the Rehabilitation of a Pit and a Quarry in southern Ontario"

ABSTRACT

For many years Ontario residents have tolerated many ills related to the industries which provide them with their social well-being. The aggregate industry in particular provides us with our roads and our buildings. It is also an extensive land user particularly near urban areas where land is at a premium and residents are fighting to rid the landscape of unsightly conditions. The practice of extracting material from the ground and leaving the site in a subsequently derelict condition has been seriously questioned and criticized.

Many after-uses of land do exist: forestry, agriculture, recreation, nature reserves, housing and waste disposal sites. Attempts at reclaiming this land for alternate uses has been carried out by some pit and quarry operators' in Southern Ontario. Two sites will be discussed outlining practices and procedures towards rehabilitation of the extracted areas.

The first site operated by T.C.G. Materials Ltd. near Brantford, Ontario comprises nearly 400 acres with final rehabilitation plans in progress. A nearby farm is now harvesting corn on a rehabilitated 6 acre portion of the site and achieving a first year return of 65 bushels per acre. Winter wheat will be harvested from another portion later this year. Normal farming operations are expected to be achieved as the soil condition improves.

The second site operated by Nelson Crushed Stone near Burlington, Ontario consists of 500 acres of which approximately 50 acres have been rehabilitated into trout ponds and pasture land. The pond, stocked with healthy rainbow trout prove that the quarry is not a cause of water pollution. This has been a point of interest for visitors, but equally important, provides the company with much better relations between their neighbors and the municipality in which they operate.

While these examples only represent a portion of the unrehabilitated lands throughout Ontario, they do illustrate the capabilities of rehabilitation. The technology of rehabilitation has progressed so that virtually any type of land use can be achieved. There are, however, many areas of rehabilitation which require further study and documentation. Attempts are now being made to encourage operators to document their rehabilitation plans so that techniques which I am about to discuss can be compared and analysed.

A CASE STUDY OF MATERIALS AND TECHNIQUES USED IN THE REHABILITATION OF A PIT AND A QUARRY IN SOUTHERN ONTARIO

Author: S. E. Yundt, B.A., M.A.
Canadian Land Reclamation Association
1977 Annual General Meeting
August 19, 1977
Edmonton, Alberta

INTRODUCTION

For many years Ontario residents and the residents of all Provinces have tolerated many ills related to the industries which provide them with their social well-being. The mineral aggregate industry in particular provides us with our roads and our buildings. "As urbanization proceeds and population increases, more roads, sidewalks, bridges, sewers and buildings are required and an increasing tonnage of construction aggregates is consumed. However, the increasing consumption of aggregates has been out-pacing the population increase....." (Hewitt and Yundt, 1971, p. 2).

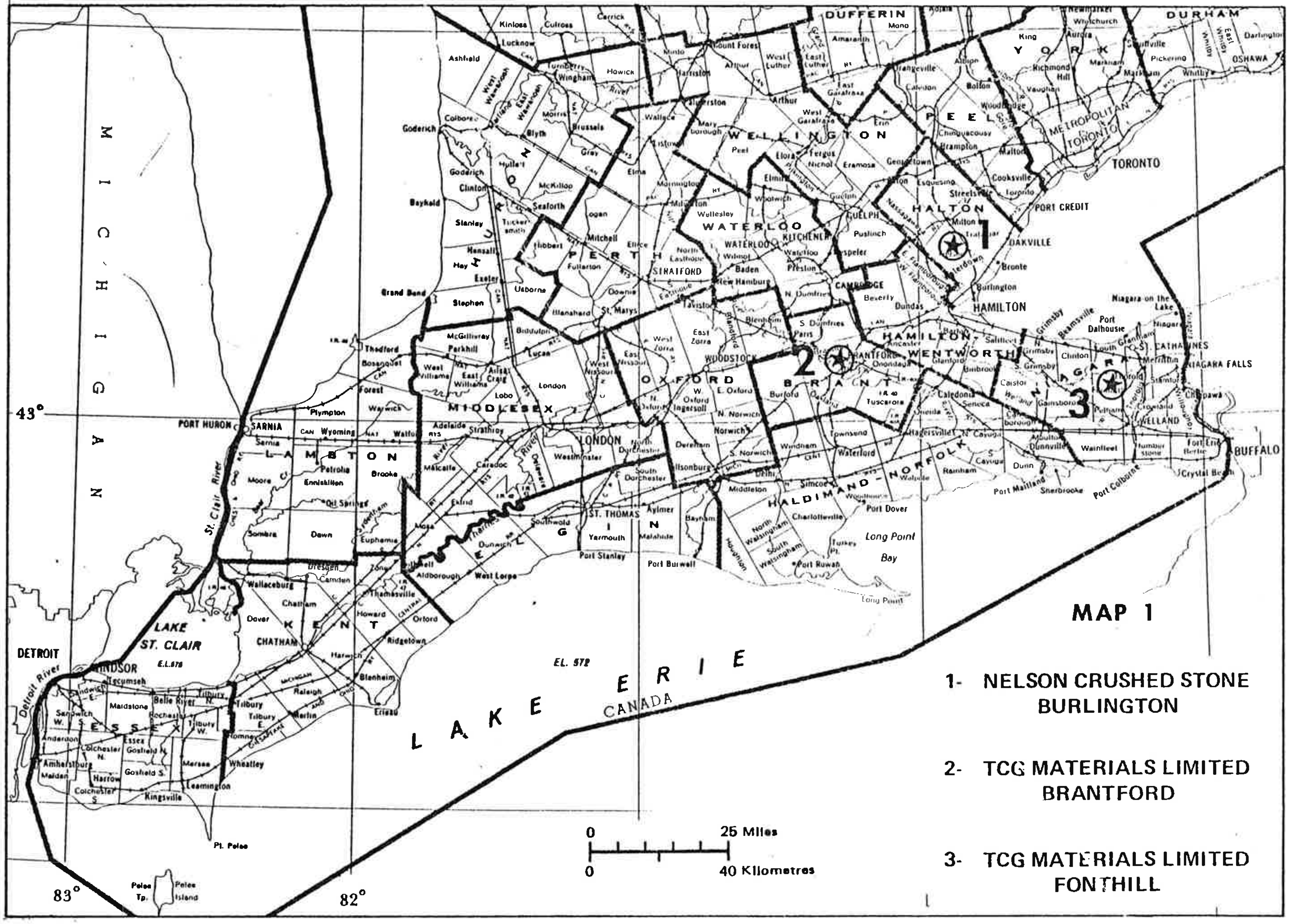
The mineral aggregate industry is thus an extensive land user particularly near urban areas where land is at a premium and residents are fighting to rid the landscape of unsightly conditions. The practice of extracting minerals and leaving the site derelict will no longer be tolerated by residents or any level of government.

Many after-uses of land do exist, such as, forestry, agriculture, recreation, nature reserves, housing and waste disposal sites. Attempts at reclaiming extracted land for alternate uses has been carried out by some pit and quarry operators in Southern Ontario. A good start has been made but there is a long rough road ahead for aggregate producers as they conform to more stringent standards.

Three specific sites have been chosen for the purposes of the present paper as follows: Nelson Crushed Stone, Burlington, TCG Materials Limited, Brantford and Fonthill (see Map 1). The Nelson Crushed Stone site was chosen because it is a limestone quarry that has been progressively rehabilitated for 20 years. It is one of the largest producing quarries in Southern Ontario and has been conscious about rapport with surrounding neighbours for years. Noise level readings have been taken at the site at each blast since the quarry started operations in 1954. The site also presents a multiple type of interim land use including, trout and waterfowl ponds, pastureland for cattle, and sloping, seeding and treeing. The rehabilitation plans for the site are not complex or detailed but the company has continually experimented with types of seed mixes, types of interim land uses and the development of both tree nurseries and fish nurseries. The final use of the site is a vast lake for recreation. The mere fact that the company has documented the bulk of its rehabilitation activities is also a valid reason for selecting this site.

The TCG Materials Limited sites were selected again because of the experimenting the company has done and because documentation was available. The Brantford site has been operated for over 60 years and is located in an area close to growing Brantford and may eventually be used for housing. The Fonthill site is critical because of the tender fruit land and although the rehabilitation is in its infancy it will be interesting to see how the cherry trees mature.

The emphasis is on documentation. The aggregate industry has been particularly negligent in documenting methods, techniques, fertilizers, seeds used and how rehabilitation is actually completed. Hopefully, this past omission will be corrected in the future.


MAP 1
1- NELSON CRUSHED STONE
BURLINGTON
2- TCG MATERIALS LIMITED
BRANTFORD
3- TCG MATERIALS LIMITED
FONTHILL
0 25 Miles
0 40 Kilometres
LAKE ERIE
CANADA
EL. 572
LAKE ST. CLAIR
MICHIGAN
DETROIT
PORT HURON
SARNIA
TORONTO
HAMILTON
BUFFALO
NIAGARA FALLS
43°
83°
82°

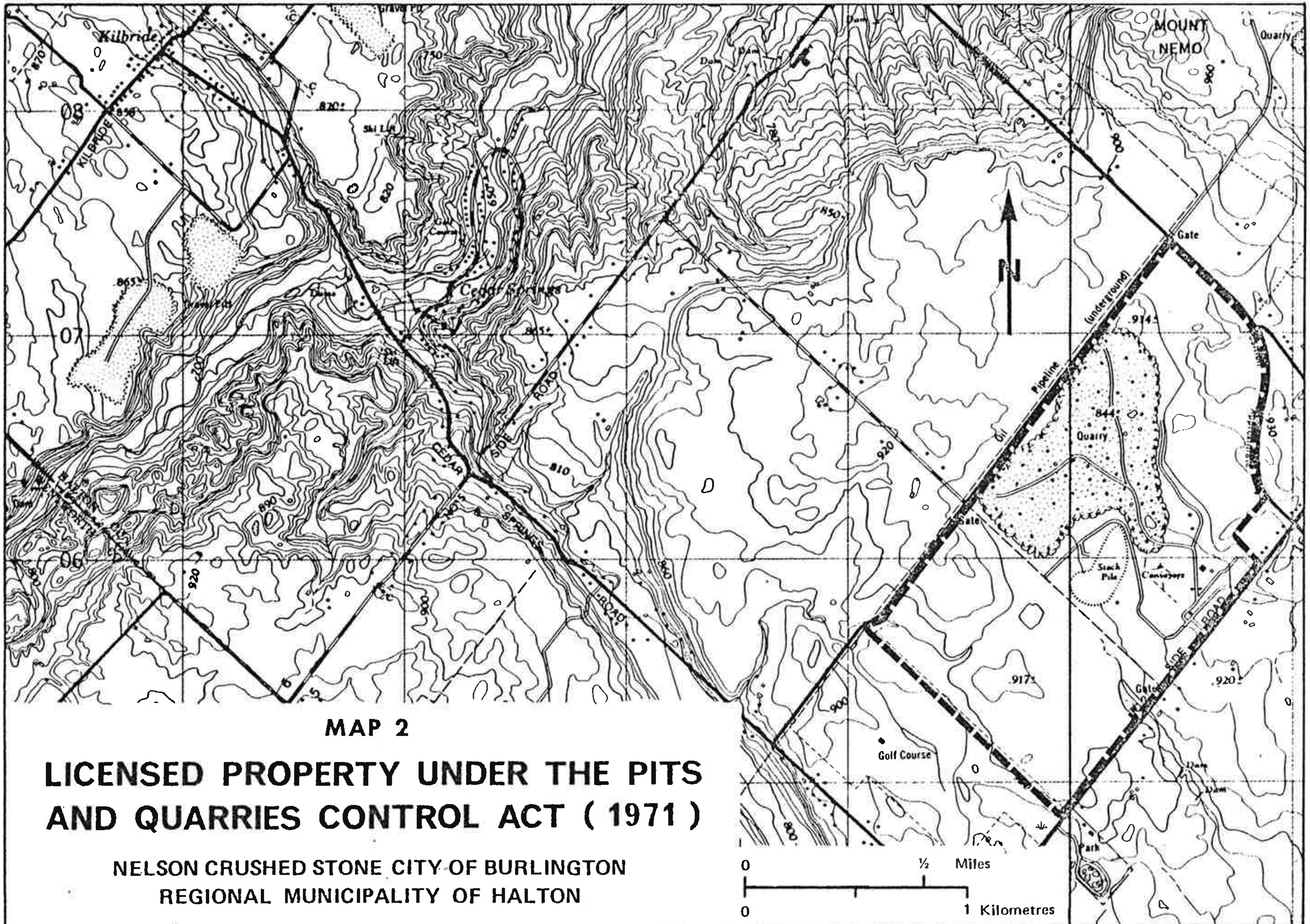
The majority of the papers presented at this meeting focus on various rehabilitation situations related to high acidity or alkalinity, low exchange capacity, high levels of carbonates and the presence of toxic compounds. The problems of rehabilitating the typical pit or quarry with virtually none of the above problems to overcome will make this paper seem simplistic. The major problem the Ontario Government faces is sufficiently stimulating aggregate producers to become serious about the progressive rehabilitation of their sites.

THE MESSAGE OF THIS PAPER IS HOW SIMPLE AND INEXPENSIVE IT REALLY IS TO PROGRESSIVELY REHABILITATE PIT AND QUARRY SITES WHEN THEY ARE PROPERLY PLANNED.

NELSON CRUSHED STONE QUARRY

This quarry was established in 1954 in the Niagara Escarpment 8 km (5 miles) north of the centre of Burlington on the Guelph Line in the Amabel and Reynales dolomite formations (Hewitt 1960, p. 115) (see Map 2). The quarry face averages 15 m (50 feet) and the yield per hectare is approximately 160 000 tonnes (180,000 tons). There is a total licensed area of 220 ha (540 acres) with 100 ha (250 acres) extracted and 120 ha (290 acres) remaining to be extracted. A total of 60 ha (150 acres) have been rehabilitated. The average annual production in recent years has been approximately 2.3 million tonnes (2.5 million tons) with a total of 38 million tonnes (42 million tons) of crushed stone produced since 1954 making this operation one of the largest in Ontario (Drury 1977).

There are three major features of the Nelson Crushed Stone Quarry that merit detailed consideration -- the trout pond and



MAP 2

LICENSED PROPERTY UNDER THE PITS AND QUARRIES CONTROL ACT (1971)

NELSON CRUSHED STONE CITY OF BURLINGTON
REGIONAL MUNICIPALITY OF HALTON

marsh areas, the pastureland and backsloping, seeding and treeing.

TROUT POND

In constructing the pond, an area of approximately 0.2 ha (0.5 acre) was extracted below the quarry floor to a depth of 3 m (10 feet). The area was seeded and trees planted around the pond. The basic function of the pond is a pumping station to keep the quarry floor dry at all times for dry extraction methods and its use as a trout pond is secondary.

The pond is stocked with approximately 800 rainbow trout ranging in size. The company maintains a small fish nursery where the trout are raised to a size suitable for transference to the pond. The healthy fish are positive proof that the quarry is not a cause of water pollution (Nelson Crushed Stone Booklet, 1973).

The pond area and surrounding marshy areas full of bulrushes (cattails) are also a natural habitat for the Canada Goose (branta canadensis) and various species of ducks especially mallard, gadwall and pintail. Contrary to the belief that aggregate extraction areas ruin wildlife habitat areas -- once the wildlife understand the operation and that they will not be injured, they are not afraid as evidenced in deer, geese and ducks located in pits and quarries. Mother ducks and their broods frequently, merrily walk across paved roads in front of 50-ton Euclid trucks fully expecting the trucks to slow down and wait until the crossing is completed.

PASTURELAND

In the spring of 1973, Nelson Crushed Stone started to develop pastureland on the filled slopes of the quarried area. They now have approximately 4.9 ha (12 acres) in pasture. The back slopes are part of a continuous program that follows along immediately behind the working face of the quarry.

The overburden being stripped from the top of the dolomite in situ, is transported to the quarry face and dumped. Then 5 to 8 cm (2 to 3 inches) of topsoil are placed over the overburden (this is the minimum to maintain grass) and fertilizer is applied. Topsoil is usually scarce and its use should be well-planned. Any topsoil that has been compacted in large piles for more than one year will lose much of its nutrient and micro-organisms, thereby reducing the quality (Ministry of Natural Resources, 1975, p. 9). This continual rehabilitation process practiced by Nelson Crushed Stone prohibits the topsoil from losing its nutrient and micro-organic properties. The fertilizer is 5-20-20 (5% nitrogen, 20% phosphorus and 20% potassium) at approximately 450 to 560 kg/ha (400 to 500 pounds per acre) per year. The slope is 3:1 and there is no subsidence. The back slopes are vegetated in grass using the following seed mix:

Creeping Red Fescue (<u>Festuca rubra L.</u>)	33%
Brome Grass (<u>Bromus inermis Leyrs</u>)	29%
Annual Rye Grass	17%
White Clover (<u>Trifolium repens L.</u>)	4%
Companion Crop (ryegrass)	17%

On the back slopes nine beef cattle are grazed each year from April to November. In 1976 the company made a profit of $30.00 per head on the cattle (Drury, 1977).

The seed mixture given above used by Nelson Crushed Stone is a slight variation of the Ontario Ministry of Transportation and Communications standard seed mixture used extensively across

Ontario, as follows sown at 90 kg/ha (80 pounds per acre);

Creeping Red Fescue (<u>Festuca rubra L.</u>)	55%	permanent grass
Kentucky Blue Grass (<u>Poa pratensis L</u>.)	25%	permanent grass
Red Top (<u>Agrostic alba L</u>.)	5%	short lived interim grass germinates quickly, will re-seed itself
Companion Crop*	12%	may be increased if hydro-seeded
White Dutch Clover (<u>Trifolium repens L</u>.)	3%	may be increased for heavier soils

*For fall seeding the mixture is supplemented by the addition of 67 kg/ha of wheat (1 bushel per acre) or 63 kg/ha of fall rye (1 bushel per acre). For spring seeding 57 kg/ha of oats (1.5 bushel per acre) is added (Ministry of Natural Resources , 1975, p. 17).

BACKSLOPING, SEEDING AND TREEING

The principle purposes for vegetating a quarry face are landscaping, the encouragement of wildlife and the control of erosion. There is some erosion on the new slopes each year after the first winter. This is a result of the seed spread in September not being able to stabilize the soil over the first winter. As will be seen from the slides there is a large amount of 5 to 10 cm (2 to 4 inch) stones remaining in the overburden and topsoil and this no doubt aids the erosion. The company feels this is not a major problem and hand broadcasts the eroded areas. After the second winter the erosion is no longer evident.

Nelson Crushed Stone estimates the cost of filling, seeding, treeing, to be in the order of $36,300 per ha ($14,700 per acre) including maintenance costs. This figure appears to be high because it is the cost for the backsloping, not including the total area of 60 ha (150 acres) considered rehabilitated but which is quarry floor needing no attention. Nelson is really building a shoreline in the backsloping process because the area will eventually be an artificial lake covering the entire quarry. The depth of the lake will be approximately 6 m (20 feet) and Nelson have purposely varied the backsloping area so it will eventually form an attractive irregular shoreline. The cost of rehabilitating including the area needing no attention is approximately $5,000 per ha ($2,000 per acre) (Drury, 1977). There may be some problems when the vegetated, treed area is flooded (stabilized to natural water table level) because as this rots the decayed vegetation floats to the surface. The company would be well advised to seek opinions on the problems that may result if the vegetation is not removed before flooding because the costs of maintenance crews to clean the decayed vegetation from the surface of the lake could be far more costly than removal before flooding.

Nelson Crushed Stone are also testing a seed mix for shaded areas of slopes or berms as follows:

75% Poa Trivialis
25% Creeping Red Fescue

The result of this test will not be known until it has gone through one full winter season. The company maintain full time nursery staff and have several tree-nursery plots - for eventual transplanting on the slopes. Originally the company planted many lombardy poplars and willows which are particularly suited to the soil conditions associated with pits and quarries. The nursery has now expanded including many tree species notably spruce and cedars.

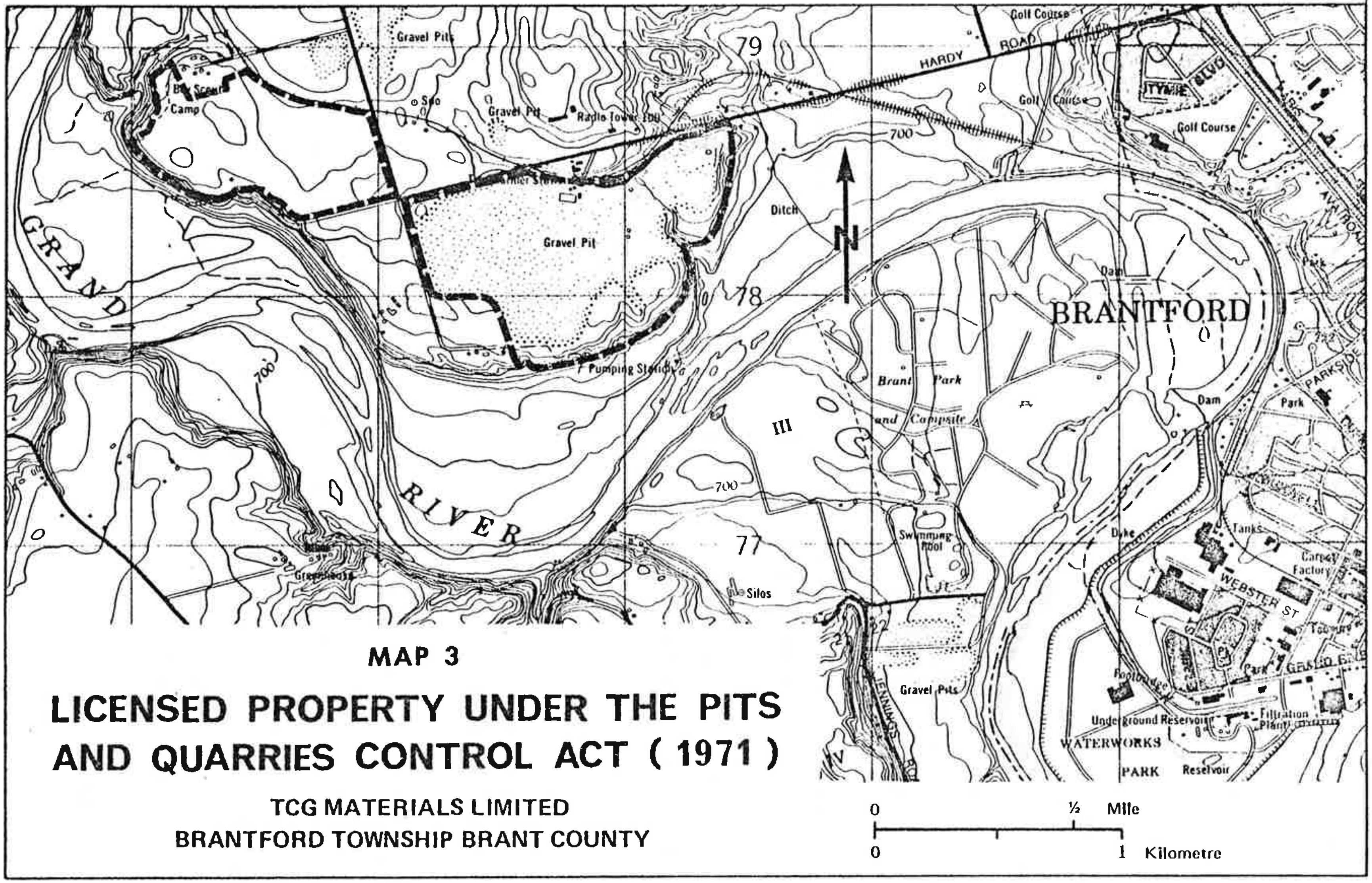
When the quarry first started, the initial overburden was stockpiled in one huge hill. This mound was seeded and later made into a ski hill complete with rope tow (Drury, 1977).

The quarry has occasionally been blamed for lowering the water table in the surrounding area. Nelson Crushed Stone continually test the water levels around the perimeter of the property with test holes and weekly readings which proves the surrounding water wells have not been lowered or interfered with. The Ministry of the Environment as well as the Ministry of Health also test the water (Nelson Crushed Stone Booklet, 1973).

The company feels there is nothing particularly sophisticated about their procedure of progressive rehabilitation and they constantly try new ideas and techniques. Nelson Crushed Stone is clearly interested in the practical side of rehabilitation.

TCG MATERIALS LIMITED

This sand and gravel pit was first operated in 1915 with materials shipped to Fort Erie. It was operated intermittently until 1956 when TCG Materials Limited took it over and it has operated coninuously since that time. The site is 3 km (2 miles) northwest of the City of Brantford in Brantford Township (see Map 3). The gravel reserves form part of an outwash spillway terrace of the Grand River system. The 0 to 2.4 m (8 feet) thick overburden is composed of stratified sand and silt overlying approximately 12 m (40 feet) of gravel on average (Hewitt and Cowan, 1969, p. 42). The yield per hectare (acre)is approximately 73 000 tonnes (80,000 tons). The average annual production from the site is approximately 635 000 tonnes (700,000 tons).



MAP 3

LICENSED PROPERTY UNDER THE PITS AND QUARRIES CONTROL ACT (1971)

TCG MATERIALS LIMITED
BRANTFORD TOWNSHIP BRANT COUNTY

TCG Materials Limited have a total of 80 ha (196 acres) licensed at this site. For the sake of simplicity this paper deals specifically with two small sections of the licensed site, that is, the 2.4 ha (6 acres) of corn land and the 2.8 ha (7 acres) of wheat land.

CORN FIELD

In 1975, TCG Materials Limited decided to experiment and try to grow corn on the floor of their Brantford pit. Between 15 to 30 cm (6 to 12 inches) of topsoil/subsoil undifferentiated was added. The 2.4 ha (6 acres) were ploughed, disked, planted, seeded and sprayed by Oakwald Farms Ltd. for TCG Materials. The starter fertilizer was 7-37-10 at 160 kg/ha (140 pounds per acre) applied with corn seed. 3.4 ka (7.5 pounds) of atrazene, 6.8 *l* (12 pints) of lasso and 545 kg (1200 pounds) of urea were used over the 2.4 ha (6 acres). Corn was selected as a matter of expediency because it is highly visible and easy to grow (Telfer, 1977).

The yield in 1975 was 3000 kg/ha (47 bushels per acre) with surrounding yields on adjacent non-extracted sites producing an average 5000 kg/ha (80 bushels per acre).

In 1976, the corn stalks were ploughed under and fertilizer 30-0-30 was used at 340 ka/ha (300 pounds per acre). The corn was planted with fertilizer starter 18-46-0 at 150 kg/ha (135 pounds per acre). The entire 2.4 ha (6 acres) was sprayed and 3.6 kg (8 pounds) of atrazene and 10.2 *l* (18 pints) of lasso were used. The corn yield in 1976 was 2100 kg/ha (34 bushels per acre) compared to 3800 kg/ha (60 bushels per acre) on surrounding farms that year. There was generally a lower corn yield in 1976.

In 1977, a subsoil/topsoil mixture was applied to the corn field (20.6 tonnes/ha, 9.2 tons per acre). The cost of this was $8.30 per tonne ($7.50 per ton). The entire 2.4 ha (6 acres) was manured in 1977 in an attempt to improve the yields. The fertilizer was 30-0-20 at 340 kg/ha (300 pounds per acre). The starter fertilizer applied with the corn seed was 12.5-50-0 at 120 hg/ha (110 pounds per acre). The entire 2.4 ha (6 acres) was sprayed with 3.6 kg (8 pounds) atrazene and 4.1 kg (9 pounds) bladex. The corn crop this year is looking the best yet and could produce up to 3800 kg/ha (60 bushels per acre) (Telfer, 1977).

TCG Materials Limited are considering switching the corn field over to alfalfa because it is a melioration plant with deep roots and after ploughing in it leaves a considerable amount of organic substance and nitrogen in the ground. There may however be a problem with the atrazene sprayed on the corn. The area was carefully lightly sprayed and kill of an alfalfa crop would probably only occur in the areas of overlapped spraying.

The land was virtually flat and has been graded and levelled five years before any crops were even considered. Stones are a problem as they continue to come to the surface each year and the ploughing must be done very carefully. Unfortunately, originally the topsoil and subsoil were not stripped off the gravel deposit separately and this had caused some difficulty. The only solution would be to add extra topsoil (Broeckel and Sterrett, 1977). Aggregate producers must now be very careful to separate the topsoil and subsoil so previous problems are overcome.

TCG Materials Limited feels quite strongly that the yields per hectare (acre) of the corn land could reach close to those of surrounding undisturbed areas if the company made the decision to put more capital into the project, for example, additional topsoil, fertilizer, etc. The company is hopeful that the land will be used for residential purposes in future and accordingly the agricultural use of the land is only an interim use so the land does not sit idle.

In 1975, the 2.4 ha (6 acres) of corn grossed $665.05 with a net profit of $78.80. In 1976, the gross was $411.93 with a net loss of $174.57 (Telfer, 1977). The company views the use of the land in crops as the value not whether or not it is profitable.

WHEAT FIELD

In 1976, 2.8 ha (7 acres) at the TCG Materials Limited Brantford pit was planted with winter wheat at 170 kg/ha (2.5 bushels per acre). This crop was chosen because the filling operation taking place on the area was not complete until early August. Then the subsoil and topsoil to cover the fill started and was completed in late August. Winter wheat was the only practical crop to plant that late in the season. The area was fertilized with 9-23-30 at 220 kg/ha (200 pounds per acre).

The land is sloped at 10 - 15% and 0.6 to 0.9 m (2 to 3 feet) of subsoil and 0.3 m (1 foot) of topsoil were used as soil cover. The site had been filled with construction site waste and only one small pocket of subsidence occurred. The land was shaped carefully to give the proper slope or contour for natural drainage.

The costs of filling, sloping, topsoiling including equipment were approximately $4450.00 per hectare ($1800.00 per acre) excluding the costs from Oakwald Farms Ltd. (Broeckel and Sterrett, 1977).

In the spring of 1977, urea was added at 185 kg/ha (165 pounds per acre). The site was not sprayed but was cultivated and packed twice. The total farming cost for the project was $193 per ha ($78 per acre). The yield in 1977 was 2300 kg/ha (34 bushels per acre) compared to 3400 kg/ha (50 bushels per acre) on surrounding unextracted natural areas (Telfer, 1977). The full cost of filling, sloping, topsoiling, seeding and cultivation was $4780 per ha ($1935 per acre).

CHERRY TREES

One other site operated by TCG Materials Limited warrants mentioning. The site is west of Fonthill, Ontario in Pelham Township. The land prior to extraction was tender fruit land for sour cherry trees. In 1977, the company decided to plant 0.8 ha (2 acres) with sour cherry trees (100) in a flat portion of the extracted pit area. The area was filled with silt and fine materials unuseable for aggregate purposes and then 0.9 m (3 feet) of topsoil (sand) was applied (Cook, 1977). As the silt ponds continue to fill and solidify the cherry orchard area will be expanded.

The soil was analysed by the Ontario Soil Testing Laboratory at the University of Guelph and found to be lacking in potash. Accordingly 1.4 kg (3 pounds) of fertilizer 0-0-60 was placed around each tree in a 1.5 m (5 foot) circle. It will take these trees five years to reach crop level and leaf analysis will be done by the University of Guelph to see if there are any other deficiencies (Ontario Soil Testing Laboratory, 1977).

There are very low maintenance costs for young trees. The costs are in the order of:

$50 per year fertilizer
$30 per year spraying
$300 for 100 1.4 cm (9/16 inch) stock sour cherry trees (Cook, 1977).

The real costs are incurred when the trees reach maturity because of the costs of picking the cherries and marketing the produce. This example is used strictly to show that there is some interesting experimenting going on in Ontario in fully extracted areas of pits. All of these activities must be encouraged, documented and expanded with the assistance of trained professional experts in the various fields.

CONCLUSIONS

Before extraction is started from any site a detailed soil survey and environmental study should be completed with full documentation including soil depth, texture, structure, stoniness, drainage, land form, land quality and agricultural production.

The topsoil and subsoil must be religiously separated when stripping takes place and these valuable materials must not be stockpiled for long periods of time because of the nutrient and micro-organic loss to the soil.

Aggregate producers should make much better use of the Ontario Soil Testing Laboratory at the University of Guelph which will analyze any soil samples and recommend fertilizers and seed mixtures. Aggregate producers should become more familiar with seeding methods as follows to produce better results:

1. seed drill or brillion seeder which place the seed in the ground and covers it with soil and no additional mulch is required.
2. broadcast seeding where the seed and fertilizer are applied to the soil surface - a mulch is necessary to protect the seed and prevent drifting during germination - in some cases a binder is needed to keep the mulch from blowing.
3. hydroseeder is the most expensive method of seeding where the seed and fertilizer are applied to the soil surface in one operation - a mulch blower then applies straw and asphalt emulsion in a second operation. The hydroseed method is recommended for dry sites with little or no topsoil, steep slopes and other difficult sites (Ministry of Natural Resources, 1975, p. 11).

For more details on grass mixtures, trees, shrubs and fertilizers for wet, fresh and dry mineral aggregate sites refer to "Vegetation for the Rehabilitation of Pits and Quarries", Ministry of Natural Resources, 1975.

Aggregate producers must make effective use of the technical expertise available in Canada, the United States, Germany and the United Kingdom on rehabilitation. Much experimentation is necessary in rehabilitating but equally the provincial governments must provide strong leadership in developing rehabilitation documentation, techniques and methods. The Provinces are responsible under The British North America Act for resources. Are they doing enough?

The filling of pits and quarries with inert wastes should be encouraged because the agricultural productivity is likely to be closer to normal in areas brought back to the same elevation as the surrounding land. The retention of moisture is the most critical factor and this is difficult if the agricultural site is in the bottom of a pit.

The progressive rehabilitation of pits and quarries is not difficult when compared to coal, salt, uranium or other mineral rehabilitation. The most difficult task is getting the aggregate producers sufficiently interested either through a rehabilitation security deposit (Ontario Mineral Aggregate Working Party Report, 1977, p. 65.), licence fees and strict legislation. All the needed technology exists -- and rehabilitation will occur either through a concerted effort by the industry or through legislative force by the Ontario Government.

The Ontario Government appointed the Ontario Mineral Aggregate Working Party in 1975 to produce a policy for mineral aggregates and to make recommendations concerning the new legislation to replace The Pits and Quarries Control Act (1971). The Report of the Working Party is now being considered by the Ontario Government and will go forward with new legislation in the near future (Ontario Mineral Aggregate Working Party, 1977).

The horizons appear to be widening as far as research, experimentation and interest in the rehabilitation of pits and quarries are concerned. However, there is not enough communication between the various groups concerned including: seed mills, nurseries, technical experts, professionals, consultants, planners, government, aggregate producers, etc. I hope that the Canadian Land Reclamation Association can be instrumental in bringing about this communication.

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PAPER

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AMELIORATION AND REVEGETATION OF SMELTER-CONTAMINATED SOILS IN THE COEUR D'ALENE MINING DISTRICT OF NORTHERN IDAHO

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ABSTRACT

Results of two experiments, one greenhouse project and one field study, indicate that high heavy metal concentrations in smelter-contaminated soils and in tree seedlings grown thereon, increase mortality rates. Factors that increased survival and growth of trees were: (i) liming the acidic, polluted soils, and (ii) using containerized seedlings. Both methods reduced the toxic potential of heavy metals in the plant and soil systems.

Species were significantly different in their respective rates of survival and growth. These differences were due primarily to inherent growth habits and tolerances to adverse growing conditions.

Field study results indicate that differences in overall survival of tree seedlings was a function of soil type (site). Findings suggest that the major cause of plant mortality, as modified by site, was high concentrations of Zn in seedling tissue and in soils.

Additional Key Words: smelter-contaminated soils, revegetation, heavy metal toxicity.

INTRODUCTION

The Coeur d'Alene Mining District of northern Idaho has long been the site of mining and smelting activities. Zinc and lead ores, spalerite and galena, respectively, are the chief mineral products of the region. A lead smelter, owned by Bunker Hill Mining Company, has operated continuously in the Kellogg Valley since 1916, and in 1928 an electrolytic zinc plant began production (7). These facilities were run without any form of pollution control until 1954 (7).

Because the lead and zinc minerals are in sulfide form, grea quantities of sulfur dioxide and metal particulates (CdO, ZnO, and PbO) have been emitted during the process of ore roasting (15,20). These pollutants subsequently fell upon the surrounding soils and vegetation (23). Oxidation of sulfur dioxide to sulfate has served to greatly lower the soil pH, which in turn has increased the solubility of metals in the soil (25). Concomitant with the several forest fires suffered by the area in the past half century, the pollution has resulted in devegetation of the adjacent terrain. The atmospheric inversion common to the valley area has compounded the pollution effects by holding the smelter gases and particulates in the local area.

OBJECTIVES

Lime has been proven to be an effective means for revegetating acidic, heavy metal contaminated soils (6). In light of such findings, two studies were conducted to determine: (1) which of the species planted was most tolerant to the adverse soil conditions, (2) the role of various metals in seedling mortalit (3) the value of lime as a means to rehabilitate smelter-contaminated soils, (4) the value of containerized tree seedlings as a tool for revegetation of polluted soils, and (5) levels of extractable heavy metals in the soil as a function of pH.

One study, a field project, involved planting four species of tree seedlings on limed and control plots of two acidic, heavy metal contaminated soils. The species selected were black locust (*Robinia pseudoacacia*), Scotch pine (*Pinus sylvestris*), Austrian pine (*Pinus nigra*, Arnold), and ponderosa pine (*Pinus ponderosa*, Laws).

The second study, a greenhouse experiment, consisted of planting black locust and Scotch pine seedlings in a smelter-contaminated soil at five pH levels.

METHODS

Experimental Design - In the field project, a split plot, randomized, complete block design was used to determine the response of four tree species grown on two soils, under two treatments (lime and control), and two planting methods (bareroot and containerized). The two sites (lead and zinc) were chosen so that a comparison between the relative effects of pB and Zn upon seedling survival could be made. Ten plots, 9.15 square meters in size, were established at each site. Five plots at each site were limed to pH 6.0 to a depth of 6 inches. Liming rates were based on buffer curves constructed in the laboratory. The soils at both sites have tentatively been classified as Dystrochrepts.

A randomized, complete block design was employed in the greenhouse study to test the response of two tree species grown on 5 pH levels of a smelter-contaminated soil. Five seedlings of each species were planted in each of the pH levels. These seedlings were grown for four months in a controlled environment chamber with a photoperiod of 15 hours. Minimum and maximum temperature settings were $10^{o}C$ and $27^{o}C$, respectively.

Soil Sampling - For the field project, soil samples were taken at depths of 0-10, 10-20, and 20-30 cm (0-4, 4-8, and 8-12 inches). The plots were sampled just prior to planting. Field samples were sieved through a 2 mm screen and the percentages of coarse fragments were calculated. Soil samples for the greenhouse experiment were taken from the pots after harvesting the seedlings. Greenhouse soils had been sieved prior to their use as planting medium. After air-drying, the percent moisture in all soils was determined by oven-drying subsamples. The sieved, air-dry samples were saved for further analyses.

Seedling Tissue Collection - At the end of the studies, seedlings were severed 1 cm above soil level. Field samples were wrapped in plastic bags, sealed, and placed in an ice chest to minimize respiration and transpiration. Seedlings that died prior to the end of the growing season were collected at death and treated in the manner previously described. These seedlings were frozen until all plants were ready for analysis. In the lab, seedlings of the same species, plot, and planting method combination were treated as one sample. This left five effective replications of each treatment on each site.

All samples, from field and greenhouse studies, were washed thoroughly to remove any external contamination and then dried at 60°C for 24 hours. The samples were then ground and stored for later heavy metal and nutrient content analyses.

Soil Analyses - Determinations were as follows: (a) soil acidity by pH meter, (b) percent organic matter by the Walkley-Black method (13), (c) extractable Na, K, Mg, Ca, Cd, Zn, Pb, and Mn in meg/100q of oven-dry soil by atomic absorption spectroscopy after neutral N NH_4OAc extraction (4, 12, 14, 20), (d) percent base saturation by summation of Ca, Mg, Na, and K, (e) percent heavy metals on the exchange by summation of Cd, Zn, Pb, and Mn, (f) exchangeable acidit by the triethanolamine, $BaCl_2$ method (4), (g) water soluble sulfate by the turbidimetric $BaCl_2$ method (4), using water in place of NaHC((h) total N by macro-Kjeldahl (4), (i) cation exchange capacity by neutral N NH_4OAc replacement and subsequent NH_3 distillation (4), (j) available P by dilute double acid extraction and colorimetric determination (4,9), (k) c:N ratio from percentages obtained in the Walkley-Black and Kjeldahl procedures, (l) bulk density by the clod method (3), (m) one-third and 15 atmosphere moisture holding capacities by pressure plate extraction (3), (n) soil texture by Bouyoucos hydrometer (3), and (o) available soil moisture by subtraction of 15 atmosphere water holding capacity from the one-third atmosphere values.

In the greenhouse study, only pH and extractable cations were determined in the soil analyses. Also, extractable Al was determined by atomic absorption spectroscopy after N KCl extraction (4).

Microbial Respiration Determination - Soil samples from the 0-4 cm depths of all field plots were brought to 50 percent field capacity and incubated for 75 hours in sealed jars. Each jar contained a 10 ml trap of 5 N NaOH. The mg of CO_2 evolved/day/100g of oven-dry soil was determined by back titrating the trap solution with 2 N H_2SO_4.

Seedling Analyses - The tissue determinations for field seedlings were as follows: (a) total N content by semi-micro Kjeldahl (4,8) using 0.3q of tissue, (b) S content was determined turbidimetrically with $BaCl_2$ using tissue that had been dry-ashed, taken up with 8 N HCl, and diluted accordingly (13), (c) P content was colorimetrically determined on an aliquot of the same sample (14), (d) K, Na, Ca, Mg, Zn, Pb, Cd, and Mn were determined by atomic absorption spectroscopy after diluting the dry-ashed sample, (e) seedling growth was recorded at the end of the growing season. The cumulative growth of each seedling was measured in cm from ground level to the tip of the apical bud for conifers. For the locust, growth was measured as the longest, developed lateral stem, and (f) survival percentages were recorded for each species-planting method combination on each plot.

Seedlings grown in the greenhouse were analyzed for all the elements discussed above. Also, the Al content of the tissue was determined by atomic absorption spectroscopy on an aliquot of the ashed sample. Growth of the seedlings grown in the greenhouse experiment was not determined.

Statistical Analyses of Data - Analysis of variance was used in determining differences among treatments and other experimental factors (site and planting method) in the field study, and species in the greenhouse study. Duncan's multiple range test was used to separate treatments in the greenhouse project and species and planting method combinations in the field experiment.

Step-wise multiple regression analyses (1) were run on the computer to find the best prediction model for survival and growth (dependent variables) of the eight species-planting method combinations used in the field study. The same procedure was used to determine the factors involved in mortality of the greenhouse seedlings. Before use in the statistical analyses, all soil properties were corrected for coarse fragment percentages and air-dry moisture values.

The step-wise procedure allows the programmer to select the specific pool of variables used in the prediction equation, and the maximum number of variables permissible in the prediction model. Fewer variables used in achieving an acceptable prediction equation means a more economical application of the model may be made.

All the soil, tissue, and experimental variables determined were used in the preliminary statistical analyses. In order to save space, only those that were significant are presented in Table

RESULTS AND CONCLUSIONS

Only the statistical relationships pertinent to the aim of the revegetation program will be presented here. Many meaningful relationships were established, but have no bearing upon the immediate plans for reclamation.

PART I: FIELD STUDY

SEPARATION OF SPECIES MEANS

Determining tree species that can tolerate harsh soil conditions has been a primary goal of rehabilitation research (10,19). The data presented in Table 2 indicates the relative success of the four tree species, grown in the field, in surviving and growing under the severe conditions. Because site stabilization is foremost in initial revegetation efforts (6,29), survival was judged more important than growth. Therefore, Austrian pine, Scotch pine, and ponderosa pine were selected as the best species to utilize in future reclamation plans.

The effect of another experimental factor, planting method, is presented in Table 3, in the form of a mean separation. It is evident that containerized seedlings were highly superior to their bareroot counterparts in terms of survival rates.

The effect of the containers upon seedling survival was two-fold. The primary effect was to buffer the root system of the seedling against the toxic constituents of the soil system. More specifically, the presence of phosphate in the rhizosphere has been shown to precipitate, and make unavailable, various heavy metal ions (5, 15).

SEPARATION OF TREATMENT, PLANTING METHOD AND SITE MEANS

The effects of treatment, planting method, and site upon several variables, dependent and independent, are shown in Table 4. Of primary interest are the effects of site upon many of the variables.

Zn concentration in the soil was found to be six times as great at the zinc site as at the lead site. In like manner, Zn concentration was three times as great in the seedlings grown at the zinc site. Cd concentration in the soil at the zinc site was also three times as great as at the lead site. When comparing the survival rates at the two sites, in light of the other data presented,

TABLE 1 - List of Variables Found to be Significant in the Statistical Analyses and their Respective Abbreviations.

Variable	Abbreviation
PART I: Field Study	
Soil Chemical Properties	
Extractable Na (meq/100g)	Na
Extractable Mg (meq/100g)	Mg
Extractable Zn (meq/100g)	Zn
Extractable Pb (meq/100g)	Pb
Extractable Cd (meq/100g)	Cd
Extractable Mn (meq/100g)	Mn
Percent Heavy Metals on the Exchange	%HM
Exchangeable Acidity	EXAC
CO_2 Evolved/Day/100g	CO2
C:N Ratio	CN
Soil Physical Properties	
Wilting Point (15 atmospheres)	WP
Site	
Zinc	ZINC
Tissue Elemental Content	
Percent Ca	%Ca
Percent Zn	%Zn
Percent Mn	%Mn
Percent P	%P
Dependent Variables	
Survival Percentage	%SUR
Growth in cm	GRO_CM
PART II: Greenhouse Study	
Soil Chemical Properties	
Extractable Zn (meq/100g)	SZn
Extractable Pb (meq/100g)	SPb
Extractable Mn (meq/100g)	SMn
Percent Al in the Tissue	TAl
Treatment (lime level)	LIMLEV
Percent Survival	PSUR

Table 2 - Mean Separation of the Percent Survival and Growth of Four Tree Species Grown on Smelter-Contaminated Soils.

Species	%Survival (mean)	Growth in cm (mean)
Austrian Pine	65.5 (A)	.42 (B)
Ponderosa Pine	61.0 (A)	.89 (B)
Scotch Pine	60.5 (A)	.57 (B)
Black Locust	36.0 (B)	2.45 (A)

Table 3 - Percent Survival of Four Tree Species as Affected by Species and Planting Method Interaction.

Species	Planting Method	%Survival (mean)
Ponderosa Pine	Container	99.0 (A)
Austrian Pine	Container	95.0 (A)
Scotch Pine	Container	94.0 (A)
Black Locust	Container	62.0 (B)
Austrian Pine	Bareroot	36.0 (C)
Scotch Pine	Bareroot	27.0 (CD)
Ponderosa Pine	Bareroot	23.0 (D)
Black Locust	Bareroot	10.0 (E)

Means with the same letter are not significantly different at the 5% level.

it is evident that the Zn concentrations (in soils and tissue), and the overall heavy metal content played a large role in seedling mortality. These metals compete with, and displace Fe and other ions in enzyme systems, altering the stereostructure and the operation of the enzyme in the plant's metabolism (15). Although the Cd concentrations found at both sites were high, no Cd was found in the seedlings. This is attributable to the Zn-Cd antagonism phenomona presented by Haghiri (12).

The effect of treatment upon extractable heavy metal concentration in the soil was much less pronounced, and often non-significant. This is probably due to the tremendous quantities of heavy metals present in the soil and the form they are in. Page (18) and Lagerwerff (15) found good correlation between the organic matter content in soils and heavy metal availability. Organic materials in the soil will chelate, and thus solubilize larg quantities of heavy metals. These chelates may be more stable than an inorganic form of the metal would be, and therefore liming will not reduce the availability of the ions significantly. The effect of lime in raising soil pH was slight below the 10 cm depth. This was due to the buffering capacity and gravelly nature of the soil, which would not permit thorough mixing of the lime at lower depths. Because the roots of both containerized and bareroot seedlings extended below 10 cm, the uptake of soluble heavy metals at those depths was not reduced by the lime treatment.

Although it did not reduce the levels of labile heavy metals in the soil, liming was significant in improving seedling survival, and highly significant in increasing growth. The Ca supplied in the lime reduced the proportion of the soil system occupied by heavy metals. The improvement shown in seedling growth is attributable to the role Ca plays in apical bud development and cell wall construction. The degree of correlation varied with species, but tissue analysis showed that percent Ca was negatively correlated wi percent Zn in the seedlings.

Table 4 - A Comparison of the Effects of Experimental Factors on the Values of Dependent and Independent Variables.

	Mean of Affected Variables								
Factor of Comparison	%Survival	Growth in cm	%Zn in Tissue	%Mn in Tissue	Zn in Soil meq/100g	Cd in Soil meq/100g	Mn in Soil meq/100g	% of Exchange in Heavy Metals	Pb in Soil meq/100g
Site									
Lead	72.00***	1.88***	.15	.065***	.044	.003	.019	1.54	.046*
Zinc	39.50	.28	.45***	.031	.276***	.009**	.031*	5.46***	.026
Treatment									
Limed	58.25**	1.39***	.31	.044	.153	.006	.027	3.30	.025
Control	53.25	.77	.29	.052**	.167	.005	.022	3.71	.047*
Planting Method									
Bareroot	24.00	.80	.24	.029					
Container	87.50***	1.36***	.36***	.067***					

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 20% level.

Planting method had highly significant effects upon all the variables concerned. Tissue levels of Zn and Mn were higher in containerized than in bareroot seedlings. This seems contradictory, but because the metabolic rate of plants varies with age, the length of seedling survival may have greatly influenced heavy metal uptake. The containerized seedlings survived until the harvest date and were able to accumulate higher concentrations of the metals. At the same time, the toxic effects of these metals in the plant were reduced by the availability of nutrient elements present in the container. The root systems of bareroot seedings were directly and totally exposed to the soil toxins at the time of planting. In conjunction with the lack of nutrients, the heavy metal concentrations in the soils increased the mortality rate of the bareroot seedlings. Containerized seedlings were able to survive the growing season, and in time could probably develop root systems that would reach below the toxic, surface layers of the soils. Once the root systems were fully developed, tree seedlings would be able to grow normally with the decrease in interference from the soil toxins.

REGRESSIONS FOR PREDICTING SURVIVAL AND GROWTH OF TREE SEEDLINGS

Because of the difficulty in establishing predictive models for the containerized seedlings, due to the buffering effect of the containers, only equations involving bareroot seedlings will be presented here. More specifically, regressions concerning bareroot seedlings of Austrian pine will be evaluated. This particular species did well in the field trials and the predictive variables are representative of the other species.

Rregression equations for prediction of survival and growth are shown in Table 5. Growth was more difficult to predict than percent survival, as evidenced by the respective R^2 values. This phenomona is in part due to the sensitivity of height growth to site conditions, and the complexity of factors affecting growth (2). Also, the internal variability of the seedlings, in terms of nutrient content, would affect their initial growth rates.

In terms of predicting survival, two factors were of great value. The microbial respiration rate (mg CO_2 evolved/day/ 100 g of soil) was highly positively correlated with survival (r=.841). The percent Zn in the tissue was negatively correlated with survival (r=.806). Also, percent Zn and percent survival were found to be highly correlated with site (r=.915 and .889, respectively). As was the case with survival, growth was correlated with percent Zn in the tissue (r=-.568), the microbial respiration rate (r=.633), and with site (r=-.592).

PREDICTION OF SEEDLING SURVIVAL RATE USING MICROBIAL RESPIRATION AS AN INDICATOR

If conditions in a soil system are adverse for plant growth and development, it follows that those conditions will affect the metabolism of soil microorganisms. Heavy metal particulate build-up and acidification of smelter-contaminated soils greatly decreases the microbial populations therein. In this study, microbial respiration rate (mg CO_2 evolved/day/100 g) was found to be highly correlated with the heavy metal content of the soil (r=-.803). Because this relationship, and that between seedling survival and microbial respiration rate, are so good, it may be possible, with further investigation, to use respiration rates as indicators of the success of future revegetation efforts.

SUMMARY

Thorough chemical and physical characterization of smelter-contaminated soils, and chemical analyses of tree seedlings grown on those soils, permitted significant regression predictions to be made concerning seedling growth and survival. Predictions based on all the measured independent variables were very effective. All variable sets used to predict growth and survival provided significant R^2 values. However, in prediction of growth, using heavy metal content of tissue, the percent variation explained was low.

Table 5 - Results of Step-wise Multiple Regression Analyses Relating Growth and Survival of Bareroot Austrian Pine to Soil and Tissue Characteristics.

Types of Data Included in the Independent Variables	Regression Equation	R^2 Values
	<u>I - Equation for the dependent variable %survival (%SUR)</u>	
All independent variables (tissue and soil values)	%SUR = 99.36 + 153.50(Na2) + 2.21(CO21) + .87(CN1) -13.00(WP1) + 179.58(%Ca)	.915**
Soil and tissue heavy metal content, exchangeable acidity, soil S content, site and treatment	%SUR = 149.24 - 442.42(Pb2) - 70.53(ZINC)	.827**
Soil heavy metal content and exchangeable acidity	%SUR = 104.36 - 706.04(Pb2) + 863.43(Mn1) - .547.62(Mn2) - 10.43(HM1) - 11.25(HM2)	.835**
Tissue heavy metal content	%SUR = 87.46 - 189.74(%Zn)	.649**
	<u>II - Equation for the dependent variable growth in cm (GRO-CM)</u>	
All independent variables (tissue and soil values)	GRO-CM = .51 + 4.45(Mg3) + 3.68(Pb2) - .02(EXAC1) +.01(CO21) - 5.23(%P)	.865**
Soil and tissue heavy metal content, exchangeable acidity, soil S content, site and treatment	GRO-CM = .66 + 9.83(Pb2) + 16.51(Cd3) - .04(EXAC3) - .29(ZINC) - 4.43(%Mn)	.788**

Table 5 - Results of Step-wise Multiple Regression Analyses Relating Growth and Survival of Bareroot Austrian Pine to Soil and Tissue Characteristics (continued).

Types of Data Included in the Independent Variables	Regression Equation	R^2 Values
	II - Equation for the dependent variable growth in cm (GRO-CM)	
Soil heavy metal content and exchangeable acidity	GRO-CM = .36 + .38(Zn3) + 6.97(Pb2) - 32.22(Cd1) - .05(HM1) - .03(EXAC3)	.605**
Tissue heavy metal content	GRO-CM = .32 - .63(%Zn)	.323*

Numerals following variable abbreviations designate the depth in the soil from which the value was obtained.
*Significant at the 5% level.
**Significant at the 1% level.

Perhaps the best predictive factor for growth and survival o the seedlings, was the respiration rate of the microbial populations. It seems feasible, at this point, that microbial respiration measurements could be used as an index to gauge the survival of tree seedlings planted on contaminated soils. This would be a rapid and inexpensive means to measure site quality of mining-disturbed soils.

Two experimental factors were especially useful in increasin the percent survival of tree seedlings. The most successful means of maximizing survival was the utilization of containerized seedlings in planting the contaminated sites. Secondly, liming the soil improved survival. Because the concentrations of the metal toxins were so great, survival could probably have been increased, to an even greater extent, by raising the pH of the soil to 7.0-7.5, instead of 6.0. Both methods of rehabilitating smelter-contaminated soils, planting containerized seedlings and liming, hold potential for future reclamation efforts.

PART II: GREENHOUSE STUDY

Percent survival of seedlings was a function of the heavy metal content of the soil, as modified by pH. Increased pH reduced heavy metal solubility and thus enhanced tree survival, as shown in Table 6. The effect of lime levels upon labile heavy metal content of the soil is presented in Table 7 in the form of a mean separation. In all instances, increased pH was associated with a decrease in the soil level of extractable metals. The specific factors involved in the multiple regression analyses for prediction of seedling survival are shwon in Table 8. Tree survival was positively correlated with soil pH (lime level) and negatively correlated with soil content of Zn and Mn. This data supports the conclusions of Haghiri (12) and Morris (17) that high concentrations of Zn and Mn can cause mortality of plants due to their interference in Fe metabolism and uptake.

The results of simple linear regression equations are contained in Table 9. Increased pH was negatively correlated with the extractability of the metals (16), which explains the value of lime as a tool for revegetating acidic, polluted soils.

The soil levels of Zn, Pb, and Mn were important in explaining the survival rates of both tree species. Highly significant negative correlations between extractable Zn, Pb, and Mn and seedling survival were measured. Mn was found to give the highest correlation for both tree species studied, followed closely by zinc. All three metals had a slightly greater impact upon black locust than on Scotch pine.

Relating tissue content of the metals to survival rates was more difficult. The survival of Scotch pine was negatively correlated to seedling content of Al. Although the relationship with Scotch pine was good, the effect of Al on black locust was positive and of low magnitude. Al toxicity is usually due to its accumulation and precipitation in the plant rhizosphere, which interferes with the plants uptake of Ca and Fe (2). In light of the data presented in Table 5, and the mode of Al toxicity, it appears that black locust may have the ability to actively exclude Al from root uptake, and prevent its translocation to aerial portions of the plant. Due to the nature of this study, it was not desirable or possible to ascertain the mechanisms of Al toxicity and/or its prevention within the tree seedlings. Scotch pine, although detrimentally affected by high concentrations of Al, was able to accumulate more Al before mortality resulted.

SUMMARY

Lime has great potential as a tool for increasing the survival of seedlings grown on smelter-contaminated soils. By increasing the soil pH and reducing solubility of heavy metal ions, lime reduces the toxic effects of those metals (6, 16). Increased levels of lime, up to pH 6.5, improved tree seedling survival.

Table 6 - The Effects of Soil pH (lime level) Upon the Survival of Tree Seedlings Grown on Smelter-Contaminated Soil.

	% Survival by Species	
Soil pH	Black Locust	Scotch Pine
4.4	0 (A)	0(A)
5.0	20 (B)	80(C)
5.5	60 (C)	40(B)
6.0	100 (E)	100(D)
6.5	80 (D)	100(D)

Means with letter are not significantly different at the 1% level.

Table 7 - Results of Mean Separation Procedures Relating the Effects of Increased Soil pH (lime level) Upon Extractability of Heavy Metals in a Smelter-Contaminated Soil.

	Extractable Metals: Means (meq/100g)		
Soil pH	Zn	Mn	Pb
4.4	.457(A)	.102(A)	.043(A)
5.0	.403(B)	.081(B)	.036(B)
5.5	.319(C)	.080(B)	.030(C)
6.0	.200(D)	.057(C)	.028(CD)
6.5	.138(E)	.050(C)	.023(D)

Means with the same letter, by metal species, are not significantly different at the 5% level.

Table 8 - Results of Step-wise Multiple Regression Analyses Relating Percent Survival of Black Locust and Scotch Pine Seedlings to Soil and Tissue Characteristics.

Types of Data Included in the Independent Variables	Regression Equation	R^2 Value
	I - Scotch Pine	
All independent variables (tissue and soil values and lime level)	PSUR = 89.27 + 14.63(LIMLEV) - 800.59(SMn)	.782**
Soil heavy metal content	PSUR = 186.79 - 130.75(SZn) -984.74(SMn)	.739**
	II - Black Locust	
All independent variables (tissue and soil values and lime level)	PSUR = 142.04 - 134.30(SZn) - 767.52(SMn)	.893**
Soil heavy metal content	PSUR = 142.04 - 134.30(SZn) -767.52(SMn)	.893**

**Significant at the 1% level.

Table 9 - Results of simple regression analyses showing the various relationships of percent survival of seedlings, soil heavy metal content, and lime level (soil pH).

Dependent Variable	Independent Variable	R Values by Species Black Locust	Scotch Pine
PSUR	SZn	-.851**	-.702**
PSUR	SPb	-.737**	-.598**
PSUR	SMn	-.882**	-.771**
PSUR	TAl	.111	-.784**
PSUR	LIMLEV	.915**	.802**
SZn	LIMLEV	-.923**	-.931**
SPb	LIMLEV	-.754**	-.777**
SMn	LIMLEV	-.852**	-.585**

**Significant at the 1% level.
Correlation coefficients are based on 25 observations.

Findings of this study indicate that Al is very toxic to Scotch pine seedlings grown on low pH, contaminated soils. Black locust seedlings were not as sensitive to Al, but were more susceptible to the toxic effects of Zn, Mn, and Pb.

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PAPER

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THE INFLUENCE OF URANIUM MINE TAILINGS ON TREE GROWTH AT ELLIOT LAKE, ONTARIO.

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JULY 1977

For submission to the Canadian Land Reclamation Association, 1977 Annual General Meeting, August 18-19, 1977 at Edmonton, Alberta.

MINERAL RESEARCH PROGRAM

MINING RESEARCH LABORATORIES
REPORT MRP/MRL 77- (OP)

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THE INFLUENCE OF URANIUM MINE TAILINGS ON TREE GROWTH AT ELLIOT LAKE, ONTARIO

by

D. R. Murray*

ABSTRACT

A four year study has been carried out to determine the ability of coniferous trees to aid in the reclamation of uranium tailings at Elliot Lake. Five species were planted: white cedar, white spruce, jack pine, scotch pine and red pine. Over 570 bare root, two year old seedlings were planted on bare tailings and in areas of established grasses. A further division was made between areas of coarse and fine tailings.

Overall survival and growth of the trees has been far below expectations from previous experience with several varieties of grasses. The criteria for assessment have been percent survival and yearly growth increases as estimated by plant height. Pine species were superior with survival percentages of 68% for bare coarse tailings, 45% for vegetated coarse tailings, and 34% for vegetated fine tailings. Cedar was the worst with survival percentages of 49%, 14% and 7% respectively. No species survived on bare fine tailings.

The survival and growth of the coniferous trees have been related to the species, environmental conditions and the tailings properties.

Key words: Coniferous Tree Growth, Tailings, Reclamation, Mine Wastes, Uranium, Elliot Lake.

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INTRODUCTION

One objective of uranium tailings reclamation at Elliot Lake is to have the waste area blend in with the surrounding environment. The natural ground cover is a mixed woodland of deciduous and coniferous trees. Coniferous tree seedlings were available in 1974 to initiate the investigation. Surface stabilization would be difficult with tree planting alone. A grass cover was established in 1973 to stabilize a portion of the tailings. Trees were planted in the vegetated tailings and in bare tailings. A comparison was drawn as to the reclamation suitability of the species and the level of effort required for the treatment.

MATERIALS AND METHODS

Two year old tree seedlings were planted in sulphide-containing uranium tailings in the Elliot Lake area in 1974. The tailings material has two distinct textural and chemical areas: coarse and fine. Each area of tailings is representative of a portion of the complete tailings pond. A description of the chemical and physical properties of the two types of tailings are presented in Table 1, and represent the material termed as bare tailings in this report. The vegetated areas have been treated with limestone and fertilizer in sufficient quantity to obtain a grass cover. The method has been described in detail in a previous report (2). Limestone and fertilizer were incorporated into the surface 15 cm to raise the pH to the range of 6.0 to 6.5 at seeding time. Various grass species were band seeded with triple superphosphate fertilizer.

TABLE 1

Characteristics of Uranium Tailings in the Elliot Lake Area (1)

Physical Properties of Uranium Tailings

Physical Properties	Coarse	Fine
Colour	White	Grey - Red or yellow
% - 325 mesh	25	85
Field capacity (%)	1.2 - 7.3	13.0 - 37.4
Wilting coefficient (%)	0.3 - 0.7	3.0 - 13.4
Air entry value (-cm H_2O)	50 - 100	235

Chemical Properties of Uranium Tailings

Chemical Properties		Tailings Coarse	Tailings Fine
pH		1.9	2.3
Cation Exchange Capacity (meq /100 g)		0.17	1.75
Toxic Metals			
(NH_4OAc* Soln)	Al	22.2	744.4
(ppm)	Fe	250	500
Available Nutrients			
Nitrogen (NO_3, ppb)		3.04	3.20
Phosphorus			
($NaHCO_3$ Soln, ppm)		0	3.9
Exchangeable Bases			
(NH_4OAc Soln)	K	0.041	0.011
(meq/100g)	Ca	7.61	37.78
	Mg	0.003	0.005
Mineral Content			
(% by weight)	Si	41.3	37.1
	Al	2.0	2.18
	S	1.18	4.25
	Fe	1.15	3.65
	K	1.12	1.14
	Ca	0.28	0.87
	Mg	0.040	0.043
	Mo, Pb	0.05	0.05
Ni, Cu, Zn, Mn, P, Cl		0.01	0.01

* Ammonium Acetate

Maintenance fertilization was carried out each year at 4 - 6 week intervals during the growing season to ensure successful establishment of the grasses.

The grasses were established in 1973, one year prior to the planting of the tree seedlings. Coniferous seedlings of jack pine, scotch pine, red pine, white cedar and white spruce were planted in four plots: vegetated coarse tailings, bare coarse tailings, vegetated fine tailings and bare fine tailings. The trees were planted at 2 meter centers. No starter tablets or soil amendments were used to aid the tree establishment. The bare tailings received no amendments. The vegetated tailings received fertilizer only as planned for adequate grass maintenance.

The distribution of the 573 trees planted is reported in Table 2. No distinction is made between the pine species and these were grouped together in the assessment.

The trees were assessed during mid-summer of each year noting the % survival and plant height. The survival for years 1 - 3 was grouped into 3 categories; dead, living and uncertain. In year 4, the survival was assessed as living or dead. The distinction was based on the presence of new growth in the fourth growing season.

Plant height data was collected for all trees classed as living and the mean value is reported for that species and year of assessment.

Several test trees were removed from each test plot to examine root growth and any distinguishing features in the soil profile and by chemical analysis of the soil. New growth tissue from the 1977 growing season was analyzed for excessive accumulation of heavy metals and radionuclides.

TABLE 2

Number of Trees Planted on Uranium Tailings

Tree Species	Vegetated Coarse Tailings	Bare Coarse Tailings	Vegetated Fine Tailings	Bare Fine Tailings
white cedar	66	63	16	16
white spruce	66	30	12	16
jack pine, scotch pine, red pine	120	96	32	40

Control tissue was taken from new growth of trees grown remote from the tailing area.

RESULTS AND DISCUSSION

Survival of the trees during the four year test period is presented in Fig. 1, 2 and 3. Trees planted on bare fine tailings did not survive beyond year 1, and therefore, are not included in the graphs. During the first two years, there was a rapid decline in all species with a levelling off in year 3 and 4 by pine and spruce species. This was most pronounced on the vegetated tailings. The difficulty in assessing plant health is shown by the vertical lines on the graphs. In many cases, the plant tops would die and new growth would come from the base of the plant or lower branches the following year. As time passed, however, the uncertainty decreased as trees either strengthened or weakened, making subsequent assessment more precise.

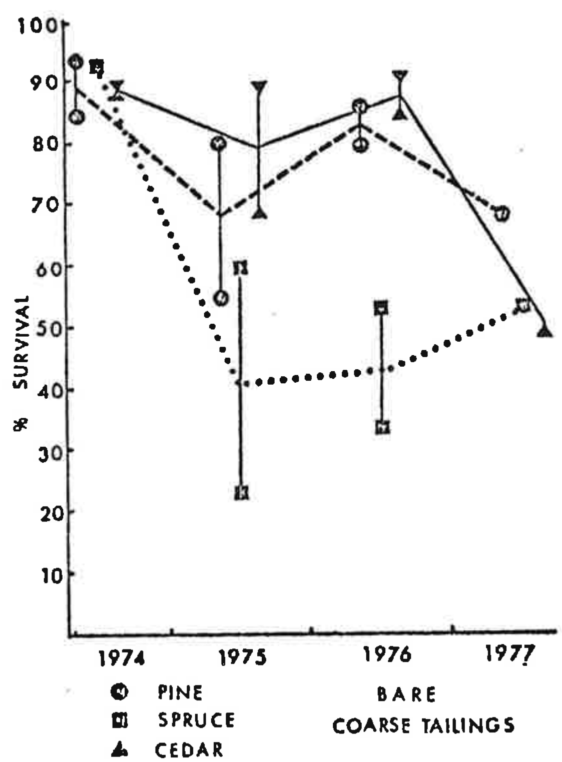

Fig. 1

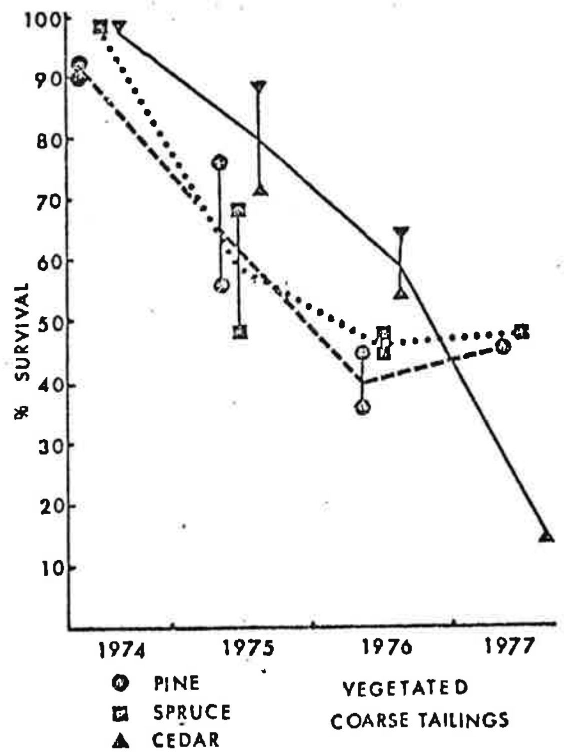

Fig. 2

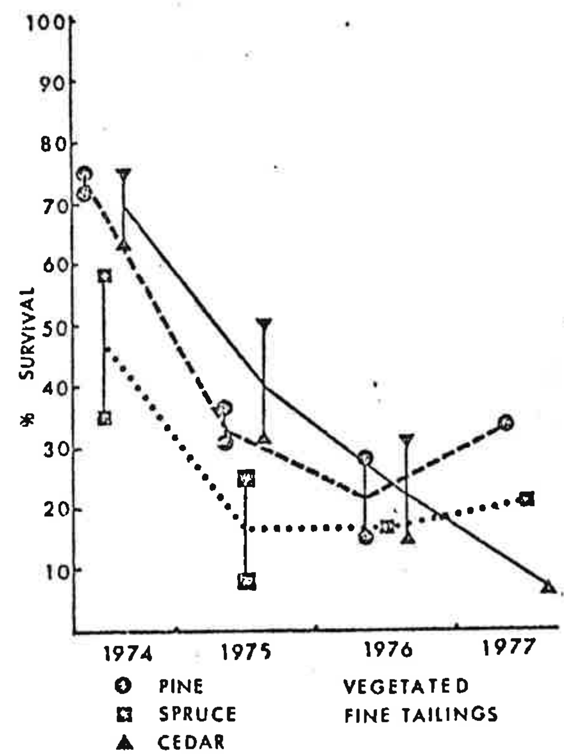

Fig. 3

Survival of Coniferous Trees in Uranium Tailings.

Pine and spruce in contrast to cedar reached a relatively stable level of survival. Survival of the trees in the fourth year is presented in Fig. 4. This data clearly illustrates marked differences between the test plots and the coniferous species. None of the species survived on bare fine tailings. Pine and spruce are consistently superior to cedar, but the tailings material and vegetation cover had a marked influence on tree survival.

Fig. 5, 6 and 7 present the annual mean growth heights of the living trees. Vegetated areas have produced better tree growth than bare tailings areas. The height must be compared with the survival to appreciate the value of various species and surface treatment. The survival and growth of trees is influenced by the tailings chemical properties, moisture conditions, and the vegetative cover present on the tailings. The aggressive uncut grass cover did not permit adequate light exposure for the small seedlings. This contributed to the poor survival rate for the trees in the vegetated areas. When the trees survived, however, and emerged above the grass, the growth of the trees was superior to those planted on bare tailings. This better growth may be attributed to the fertilization program for grass establishment and the protection of the trees by the grass from unstabilized wind-blown tailings.

The trees on bare coarse tailings were exposed to excessive reflected sunlight and heat because of the white colour. The unstable surface has been injurious to the seedlings because the erosion of the surface has exposed roots, has dried the surface, and has provided a source of

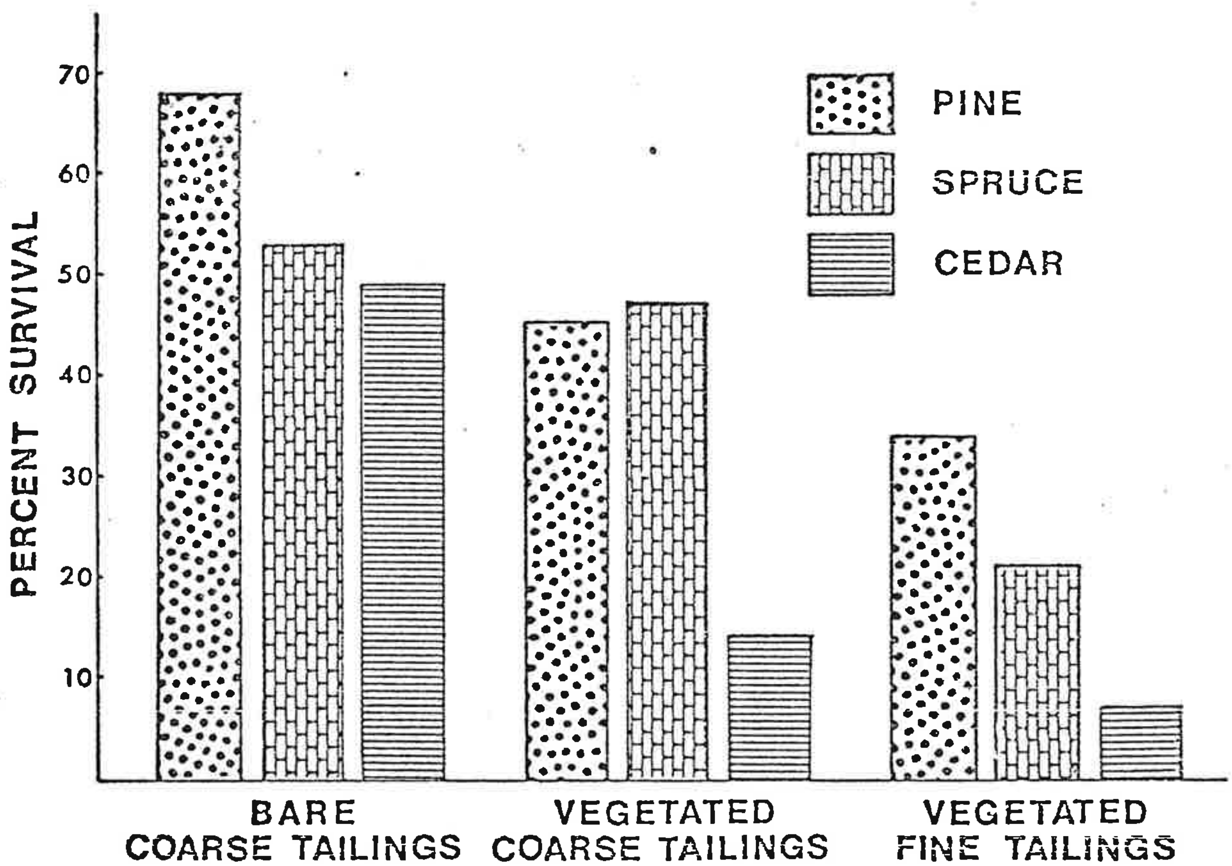

Fig. 4: Survival of Coniferous Trees during the fourth year of growth on Tailings.

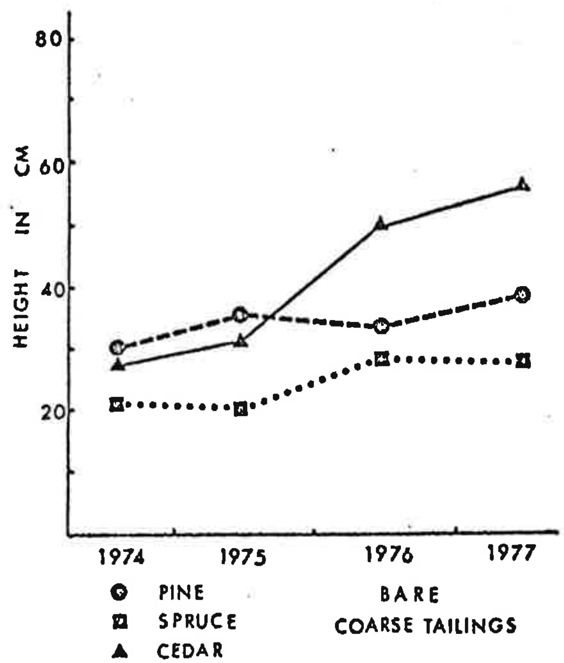

Fig. 1

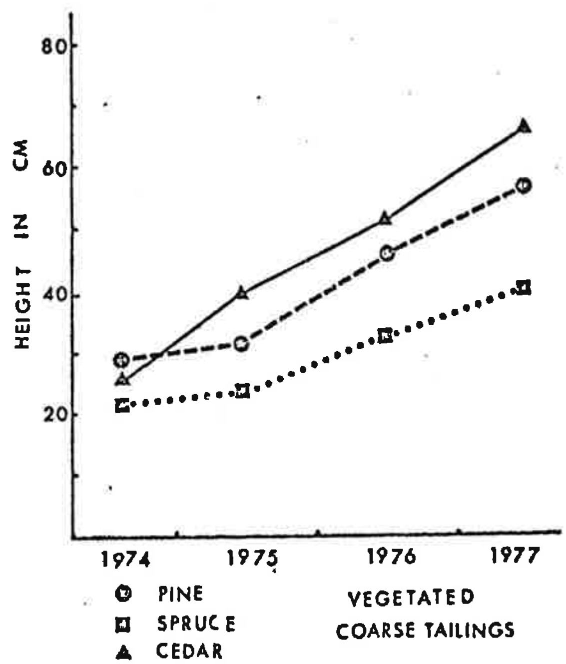

Fig. 2

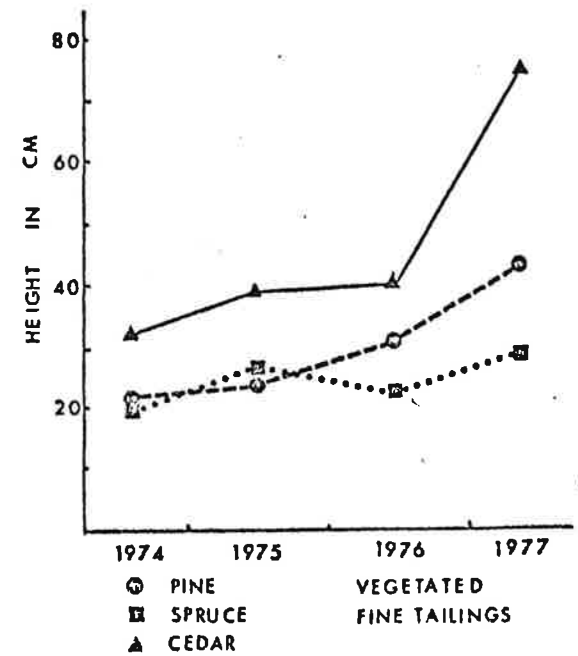

Fig. 3

Coniferous Tree Growth on Uranium Tailings.

wind-blown particles.

The tailings moisture level was critical for establishing grasses and similarly should affect tree growth. On coarse tailings, drought conditions tended to occur rapidly, whereas on fine tailings, flooding was common. The death of all plants on bare fine tailings was partly attributed to the 5 weeks of flooding which occured each spring and the subsequent soil moisture levels (30% - 40%) for the remainder of the year. This caused poor aeration of the root zone, and the death of the tree species planted. In contrast, tree survival was better on the coarse tailings due to a more suitable moisture balance than that present in the fine tailings. Water available for tree growth has been considered equal for the bare coarse and vegetated coarse tailings plots. Rapid drying occurred on the bare tailings while competition for moisture occurred on vegetated tailings.

The chemical properties of the tailings are noxious to grasses and amendments were necessary to establish grasses. No natural encroachment had occurred over the 6 year period prior to this study. Heavy metal content and low pH are closely related and would account for the lack of natural recolonization by grasses or trees. This also explains the lack of success of any vegetation on bare fine tailings. The coarse tailings has shown some acceptance of tree seedlings. This unexpected result without soil treatment could be accounted for by the coarse texture of the material and the effect of leaching of heavy metals from the surface profile creating a more favourable micro-environment. Due to the downward movement of water and chemicals the pH has increased from pH 1.9 to between pH 3.5

and pH 4.0. In the vegetated areas the soil has remained at ≥ pH 5 and the grasses have been supplied periodically with nutrients. The depth of root penetration in coarse tailings has been 15 - 20 cm while in the fine tailings the root penetration has been 5 - 10 cm. In fine tailings this shallow depth was definitely marked with a change in pH from the surface at pH 5.5 to pH 3.0 at a depth of 15 cm. With coarse tailings the change of pH with depth was small, less than 1 pH unit.

Of the species studied, the pine is the preferred species after 4 years of growth. Cedar was thought to be better for the first 3 years, but survival continued to decrease with time; survival of cedar was the poorest at the completion of this study. Spruce appeared poorest at first, but have been more persistent if they survive the first year.

The root growth of the trees has been restricted in all cases to a shallow depth of tailings. Cedar produced a large number of fine roots with no definite main root and the depth was limited to 20 cm with the healthiest plants. Spruce produced numerous lateral roots just below the surface which were often up to 1 meter in length. On the bare tailings these roots had become exposed because of erosion of the loose tailings. There were not many fibrous roots and if present they were short and stubby. Pine roots formed major branch roots, but showed definite bending of the root from vertical penetration to horizontal growth. In fine tailings this was 5 - 10 cm, while in coarse tailings it was 15 - 20 cm. Very few fibrous roots were present and the root hairs were short.

In all cases the roots were black in colour. This could be an indication of poor compatibility of the plants with the micro-environment within the tailings. The balance between survival and death may be a very narrow range which is dependent on the extent of injury to the root tissue. The lack of fibrous roots and stubby root hairs may be an adaptation of the tree to this environment.

Spruce and cedar normally have shallow root systems. Cedar prefer a non-acid soil with adequate moisture, thus the acid in dry conditions of the tailings may contribute to the lack of tree success. Spruce will tolerate slightly acid soils, but prefer a calcareous based soil for best growth. Pine prefer slightly acid soils and poor quality sand textured soils. Normally pine have moderately deep roots. The tailings texture and acidity are more suitable to pine trees, but excess acidity would hamper good growth.

Thus it is not surprising that pine is the preferred species for tailings reclamation. Growth of trees on bare coarse tailings indicates that the material is not completely adverse to tree growth. Growth is not exceptional, but the effort expended on establishment is minimal.

CONCLUSIONS

The use of coniferous trees for reclamation of uranium tailings does not appear to be a rapid solution. The survival and growth rate are not sufficiently encouraging to depend entirely on trees. Surface stabilization of bare tailings was not obtained with trees as it was with a grass cover. The use of fertilizer tablets may increase tree survival and growth during future test work.

Although tree survival was optimal on bare coarse tailings, the best growth rate occurred in the vegetated plots and is attributed to the following factors:

1) Retention of nutrients by the organic layer.

2) Protection from abrasion and erosion by the grass cover.

Of the species tested, pines are the most suitable conifer species for growth on uranium tailings.

ACKNOWLEDGEMENT

The author wishes to acknowledge the fruitful discussion and assistance of Dr. D. W. Moffett.

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PAPER

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WEATHERING COAL MINE WASTE
ASSESSING POTENTIAL SIDE EFFECTS AT LUSCAR ALBERTA

by

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Title of Paper: "Weathering Coal Mine Waste.Assessing Potential Side Effects at Luscar, Alberta"

ABSTRACT

In some areas the accelerated weathering of material disturbed by coal mining operations releases toxic concentrations of elements present. Also, water seeping through the mine waste may become quite acid. Knowledge of these detrimental side effects has been a concern to those planning coal mining operations in Alberta.

A study was undertaken to determine if there is a potential for adverse side effects resulting from weathering mine waste derived from the Luscar Formation inthe Alberta foothills. Steps involved included:

- mapping geological stratigraphy and lithology
- taking a continuous core through a representative profile
- performing detailed geochemical analyses on the core

Chemical analyses were selected to reveal base conditions present in the overburden profile and the potential for change during weathering. Constituents identified included total sulphur, macro and micro nutrients, water soluble cations and anions, extractable cations, and trace elements. Key indicators such as neutralization potential, cation exchange capacity and sodium absorption ratio were also determined.

The analyses revealed that:

- the total sulphur content is very low so acid mine water will not be a problem
- only normal amounts of water soluble ions, extractable ions or trace elements were found. Consequently weathering is not likely to release toxic concentrations of these elements.

- sodium concentrations in the hanging wall materials which will be most affected by mining were found to be suitable for revegetation.

It is concluded that weathering of the material disturbed by mining will not have any harmful side effects. Consequently, from a geochemical point of view, waste materials may be placed in waste dumps in any order convenient to the mining program.

It is also concluded that the investigation program reported was appropriate to evaluate conditions at the Luscar Site. Detailed investigation programs required in the U.S. where adverse side effects do occur are not warranted in this area.

WEATHERING COAL MINE WASTE
ASSESSING POTENTIAL SIDE EFFECTS AT LUSCAR ALBERTA

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D. E. Ryder, Cardinal River Coals Ltd.

1. INTRODUCTION

In some areas of the world weathering of mine waste has created adverse side effects by releasing toxic concentrations of certain elements or by creating acid mine water. Knowledge of these detrimental side effects has been a concern to those planning coal mining operations in Alberta.

An investigation was undertaken to determine potential side effects from weathering of the Luscar Formation in the Foothills region at Luscar, Alberta. The paper which follows describes the sampling and testing program undertaken, presents the results and interprets them. Detailed chemical analysis performed on representative samples formed the core of the program. Interpreted results compare favourably with observations at old waste dumps in the area.

2. SAMPLING PROCEDURES

The site geology was studied to identify a representative stratigraphic profile. A core hole was then drilled at that location and the core logged and sampled for chemical testing.

Samples were selected from the core in accordance with selection procedures outlined in Table 1.

TABLE 1 - SAMPLE SELECTION PROCEDURES

1. Each lithographical unit more than two feet thick sampled separately.

2. Sandstone - sample entire bed up to 20 feet thick
 - grab samples selected at 5 foot intervals combined to make a representative sample.

3. Siltstone/Shale - sample entire bed up to 10 feet thick
 - grab samples selected at 2 foot intervals combined to make a representative sample.

4. Strata of lesser thickness - samples taken at top middle and bottom combined to make a composite sample.

3. CHEMICAL TESTING PROGRAM

Each sample was subjected to chemical tests indicated in Table 2. It shows the chemical analyses performed, the basic test methods and the reason for each test.

Results of the chemical analyses are summarized in Table 3. For comparison a summary of normal and hazardous concentrations of micro nutrients and trace elements is shown in Table 4.

TABLE 2

DETAILED CHEMICAL TESTING PROGRAM

CHEMICAL PARAMETERS	PROPOSED ANALYTIC PROCEDURES	PURPOSES OF TESTING
TOTAL SULPHUR	Leco-Induction Furnace (Potassium Iodate Method)	a) Define sulphur concentration and project pyritic sulphur content. b) Establish an acid-base account.
NEUTRALIZATION POTENTIAL (ESTIMATE OF TOTAL CALCIUM CARBONATE)	Acid Titration	a) Define carbonate content. b) Establish an acid-base account.
pH	1:1 Paste + pH Meter	a) Define H^+ ion concentration. b) To be used in lime reclamation c) Evaluate pH conditions as favourable to vegetation.
MACRO-NUTRIENTS NITROGEN (NO_3^{-2}) POTASSIUM (K) PHOSPHOROUS (P)	 Nitrate-Specific Ion Electrode Extract-Atomic Absorption Olson-Bicarbonate Method	a) Define levels. b) Evaluate revegetation potential. c) Fertilization recommendation
MICRO-NUTRIENTS COPPER (Cu) ZINC (Zn) LEAD (Pb) IRON (Fe)	 DPTA Extractable DPTA Extractable DPTA Extractable DPTA Extractable	a) Define levels. b) Evaluate revegetation potential. c) Fertilization recommendation.
SALINITY (ELECTRICAL CONDUCTIVITY) E.C.	Conductivity Bridge	a) Define base levels. b) Revegetation significance and potential
WATER SOLUBLE CATIONS CALCIUM (Ca^{+2}) MAGNESIUM (Mg) POTASSIUM (K) SODIUM (Na^+)	Saturation Extract of Paste and Atomic Absorption Flame Emission Method	a) Define base levels. b) Prediction of mine effluent constituents. c) To be used in determining Sodium Adsorption Ratios.
WATER SOLUBLE ANIONS SO_4^{-2} NO_3^{-2} HCO_3 Cl	Saturation Extract of Paste Barium Chloride - Spectrophotometer Nitrate - Electrode Acid Titration Chloride - Electrode	a) Define base levels. b) Predice mine effluent levels and pollution evaluation. c) To be used in interpreting presence of major salts
CATION EXCHANGE CAPACITY (C.E.C.)	Ammonium Acetate Method	a) Define base levels b) Significance to revegetation potential c) To be used in calculating ESP* and/or SAR**
SAR and/or ESP	$SAR = Na^+/(\frac{Ca + Mg}{2})^{1/2}$ Na = Sodium, meq/l Ca = Calcium, meq/l Mg = Magnesium, meq/l $ESP = (Na_e^{***} - Na_s^{****})100/C.E.C.^{*****}$	a) Define base levels. b) Predict reaction of clay to weathering. c) Revegetation potential.

* (ESP) - Exchangeable Sodium Percentage

** (SAR) - Sodium Adsorption Ratio

*** (Na_e) - NH_4OAc Extractable Sodium, meq/100g

**** (Na_s) - Water Soluble Sodium, meq/100g

***** (CEC) - Cation Exchange Capacity, meq/100g

CHEMICAL PARAMETERS	PROPOSED ANALYTIC PROCEDURES	PURPOSES OF TESTING
TRACE ELEMENT(S), CONTENT OF: MERCURY (Hg) LEAD (Pb) CADMIUM (Cd) SELENIUM (Se) BORON (B) MOLYBDENUM (Mo) NICKEL (Ni)	 Flameless Absorption Method Atomic Absorption Method Atomic Absorption Method Hot Water Soluble-Spectrophotometer Hot Water Soluble-Spectrophotometer Flameless Atomic Absorption Atomic Absorption Method	a) Define base levels. b) Predict revegetation potential c) Predict mine effluent pollution

TABLE 3

RESULTS OF CHEMICAL ANALYSIS

LITHOLOGY	DEPTH INTERVAL (FEET)	SAMPLE INTERVAL (FEET)	TOTAL SULPHUR (ppm)	TOTAL SULPHUR AFTER ACID LEACH (ppm)	NEUTRALIZATION POTENTIAL (TONS OF CaCO3 EQUIVALENT PER 1000 TONS OF SOIL)	MOISTURE SATURATION (%)	SOIL PASTE pH *	SOIL PASTE pH	CONDUCTIVITY OF SATURATION EXTRACT (millimhos/cm.)	WATER SOLUBLE CATIONS (MeQ/L) Ca	Mg	Na	K	EXTRACTABLE CATIONS (MeQ/100gms) Ca	Mg	Na	K
SANDSTONE	8 - 28	5	263	215	40.5	49.5	8.2	8.2	0.59	1.18	1.65	2.07	0.51	17.53	3.40	1.32	0.59
SANDSTONE	28 - 48	5	378	NOT TESTED	75.6	45.2	8.3	8.1	0.53	1.13	1.02	2.34	0.51	34.60	5.35	1.19	1.02
SANDSTONE	48 - 68	5	363	NOT TESTED	159.	47.7	8.5	8.3	0.66	1.45	1.32	2.87	0.68	125.61	4.94	4.20	1.34
SANDSTONE	68 - 79.5	5	237	NOT TESTED	79.3	41.2	8.6	8.1	0.60	0.98	0.55	2.29	0.51	5.32	5.14	1.67	0.97
SHALE/SANDSTONE	79.5 - 82	T-M-B	304	219	138.	52.9	8.6	8.0	0.85	1.70	1.88	3.61	0.99	11.09	5.45	1.24	1.11
SHALE	82 - 83	T-M-B	311	245	68.8	44.7	8.5	8.1	0.54	1.01	1.20	1.99	0.63	10.17	4.84	0.87	0.98
SANDSTONE	83 - 94	5	326	230	76.8	49.7	8.0	8.1	0.57	1.20	1.28	1.62	0.83	22.55	6.17	0.72	1.20
SHALE/SANDSTONE	94 - 98.5	2	422	388	141.	57.8	8.5	8.0	0.67	1.78	2.14	2.00	0.74	12.75	7.82	0.74	1.24
SANDSTONE	98.5 - 103	5	274	NOT TESTED	221.	45.8	8.2	7.8	0.83	1.24	3.54	2.57	1.02	144.00	7.72	0.60	1.01
SHALE	103 - 104	T-M-B	703	NOT TESTED	50.8	56.0	8.3	7.9	0.63	1.79	1.91	1.49	0.82	9.87	5.57	0.62	1.19
SHALE	104 - 114	2	546	437	118.	59.7	8.0	7.9	0.62	1.40	1.66	1.69	0.77	13.11	7.61	0.65	1.07
SHALE	114 - 122	2	753	674	60.8	43.0	8.0	7.8	0.67	1.94	1.78	2.21	0.54	11.95	5.04	0.69	0.77
COAL	122 - 187	10	2919	2892	14.8	72.2	8.5	8.3	0.27	0.53	0.38	1.87	0.10	13.05	1.54	0.53	0.34
SANDSTONE	187 - 207	5	3292	NOT TESTED	2.5	48.5	7.7	6.4	1.45	7.02	5.51	1.81	0.37	1.30	1.01	0.61	1.09
SANDSTONE	207 - 227	5	1429	NOT TESTED	122.	47.8	8.5	7.7	1.31	5.57	7.32	2.03	1.36	25.37	15.23	0.71	1.17
SANDSTONE	227 - 247	5	820	813	141.	43.4	8.8	8.1	0.73	1.68	2.84	1.52	0.81	22.08	17.90	0.70	0.66
SANDSTONE	247 - 267	5	321	NOT TESTED	240.	48.0	8.3	8.4	1.10	1.14	4.12	1.58	3.21	86.40	34.16	0.92	1.95
SANDSTONE	267 - 278	5	2395	NOT TESTED	186.	49.0	8.8	8.1	1.16	1.73	2.84	3.74	2.91	53.96	32.92	1.54	1.78
SHALE	278 - 282	2	6299	6274	76.6	42.1	9.0	8.3	1.03	0.73	0.55	8.79	0.40	10.63	8.13	3.59	0.67
SANDSTONE	282 - 302	5	355	NOT TESTED	68.3	49.5	8.8	8.1	0.82	0.70	0.53	6.79	0.85	53.41	8.85	3.04	1.42
SANDSTONE	302 - 320	5	.856	NOT TESTED	124.	53.5	9.4	8.6	1.35	0.32	0.72	12.53	0.72	63.48	14.61	6.63	1.69
SANDSTONE/SILTSTONE	320 - 340	5	1190	1115	88.3	49.7	9.4	8.8	1.11	0.24	0.39	10.92	0.38	30.52	9.05	7.28	1.21
SANDSTONE/SILTSTONE	340 - 356	5	579	NOT TESTED	96.8	61.5	9.1	8.6	1.75	0.52	0.72	6.35	2.46	61.15	25.72	5.00	5.44
SANDSTONE	356 - 370	5	1217	NOT TESTED	185.	50.0	8.9	8.3	0.97	1.75	2.45	2.62	2.93	59.01	41.15	1.12	2.05
SILTSTONE/SANDSTONE	370 - 399	5	934	849	148.	59.9	8.8	8.4	0.70	0.63	0.70	3.50	1.51	123.04	17.99	4.02	4.09
SILTSTONE	399 - 421	5	1491	NOT TESTED	106.	66.7	9.2	9.2	1.32	0.20	0.15	13.53	0.56	79.66	11.11	13.70	3.13
CONGLOMERATE	421 - 426	T-M-B	4642	3937	208.	62.2	9.2	8.9	2.00	0.39	0.54	15.83	2.89	78.31	23.05	10.87	6.52
SILTSTONE	426 - 446	5	3877	NOT TESTED	124.	65.9	9.3	9.4	1.63	0.17	0.12	20.49	0.82	70.83	12.76	14.13	2.53
SHALE	446 - 456	2	6065	5610	248.	62.7	9.4	9.6	1.11	0.21	0.14	15.05	0.44	286.77	12.14	10.33	3.37
SHALE/SILTSTONE	456 - 466	2	8415	NOT TESTED	> 250.	60.1	9.6	9.6	1.31	0.18	0.43	13.05	0.32	314.34	15.23	3.80	1.36
SHALE/SILTSTONE	466 - 478	2	5953	5659	> 250.	60.0	9.4	9.4	1.10	0.16	0.33	10.57	0.55	286.15	6.59	6.85	3.04
SHALE/SILTSTONE	478 - 488	2	2298	NOT TESTED	200.	60.8	8.9	9.4	1.40	0.30	0.65	10.48	0.31	176.72	5.57	12.39	1.63
SHALE/SANDSTONE	488 - 496	2	1017	NOT TESTED	239.	62.2	9.3	9.0	1.42	0.20	0.27	10.57	0.72	46.94	8.65	9.24	2.40

NOTES:
(1) ------ Indicates minimum
(2) ——— Indicates maximum
(3) * pH testing performed previously on the samples at same intervals
(4) ** (Negligible) - no testing necessary since corresponding pH values are less than 8.8.

TABLE 3 (contd)

RESULTS OF CHEMICAL ANALYSIS

	DEPTH INTERVAL	WATER SOLUBLE ANIONS (MeQ/L)					MACRO NUTRIENTS (ppm)			MICRO NUTRIENTS (ppm)				CATION EXCHANGE CAPACITY	SODIUM ADSORPTION RATIO	EXCHANGEABLE SODIUM PERCENTAGE	TRACE ELEMENTS (ppm)						
LITHOLOGY	(FEET)	SO_4	NO_3 as N	HCO_3	CO_3	Cl	NO_3 as N	K	P	Cu	Zn	Mn	Fe	(MeQ/100gms)			Hg	Pb	Cd	Se	B	Mo	Ni
SANDSTONE	8 - 28	1.44	0.05	3.1	NEGLIGIBLE**	2.05	2.3	385	2.0	4.4	3.2	235	584.0	10.43	2.0	11.8	0.12	9.1	0.1	0.10	0.03	6.50	16.9
SANDSTONE	29 - 48	1.34	0.03	3.4	NEGLIGIBLE	1.20	1.0	399	3.0	3.2	2.6	277	624.0	8.91	2.2	12.2	0.14	26.9	0.2	0.30	0.10	6.70	15.8
SANDSTONE	43 - 69	1.69	0.03	3.8	NEGLIGIBLE	1.03	0.8	525	5.0	4.5	2.0	185	707.0	9.13	2.4	51.0	0.13	10.7	0.1	0.50	0.14	11.20	21.9
SANDSTONE	68 - 79.5	0.94	0.01	4.1	NEGLIGIBLE	0.94	0.7	379	1.5	3.8	3.3	61	468.0	8.48	2.3	13.6	0.10	9.6	0.4	0.34	0.16	4.60	16.3
SHALE/SANDSTONE	79.5 - 82	1.25	0.01	7.0	NEGLIGIBLE	0.77	0.9	433	6.0	5.9	3.9	13.9	649.0	8.26	2.7	12.7	0.13	7.7	0.3	0.24	0.13	5.80	16.8
SHALE	82 - 83	0.94	0.02	4.6	NEGLIGIBLE	0.43	1.7	383	0.6	4.5	2.8	13.0	584.0	7.17	1.9	10.7	0.11	24.9	0.5	1.10	0.13	4.10	22.8
SANDSTONE	83 - 94	1.38	0.03	4.8	NEGLIGIBLE	0.68	1.1	469	0.5	3.7	4.3	11.2	422.0	9.45	1.5	6.8	0.13	19.0	0.7	1.12	0.16	3.00	20.5
SHALE/SANDSTONE	94 - 98.5	1.16	0.01	6.0	NEGLIGIBLE	0.43	2.2	484	0.5	6.9	5.0	15.3	372.0	8.59	1.4	7.3	0.12	10.3	1.2	0.70	0.20	3.30	15.4
SANDSTONE	98.5 - 103	1.44	0.03	6.8	NEGLIGIBLE	0.60	1.0	394	17.0	2.6	2.8	32.2	808.0	6.63	1.7	7.2	0.09	9.8	0.7	0.88	0.14	4.50	7.9
SHALE	103 - 104	1.56	0.05	4.6	NEGLIGIBLE	0.34	0.8	465	8.0	4.3	3.0	9.1	164.0	8.80	1.1	6.1	0.16	9.7	1.0	0.99	0.72	3.90	23.6
SHALE	104 - 114	1.13	0.01	5.4	NEGLIGIBLE	0.34	0.1	420	5.0	5.4	2.8	12.0	302.0	7.61	1.4	7.2	0.35	10.8	1.0	0.90	0.16	7.40	15.8
SHALE	114 - 122	2.38	0.02	4.5	NEGLIGIBLE	0.26	0.4	302	3.0	6.0	5.6	6.6	209.0	8.80	1.6	6.6	0.33	9.4	0.4	0.46	0.18	2.60	18.2
COAL	122 - 187	0.78	0.01	2.0	NEGLIGIBLE	0.09	0.5	18	1.0	0.8	1.2	0.8	20.2	5.11	2.7	13.1	0.07	1.7	<0.1	0.35	<0.02	0.61	0.2
SANDSTONE	187 - 207	12.13	0.07	0.0	NEGLIGIBLE	0.09	1.0	428	5.0	2.1	4.4	19.4	1268.0	5.49	0.7	9.5	0.25	9.4	0.1	0.90	0.47	11.50	61.4
SANDSTONE	207 - 227	8.91	0.05	7.1	NEGLIGIBLE	0.43	3.2	459	4.0	6.1	5.8	18.0	1294.0	5.11	0.8	11.9	0.13	11.0	0.4	0.28	0.18	5.60	46.0
SANDSTONE	227 - 247	1.13	0.04	6.3	NEGLIGIBLE	0.34	0.7	260	6.0	5.6	2.0	9.8	992.0	1.82	1.0	34.6	0.09	9.5	0.3	0.03	0.28	10.10	31.0
SANDSTONE	247 - 267	1.25	0.02	8.4	NEGLIGIBLE	0.51	0.4	763	7.0	3.2	2.8	13.9	749.0	3.21	1.0	23.1	0.10	10.4	0.2	0.14	0.28	11.10	21.9
SANDSTONE	267 - 278	1.16	0.06	7.5	NEGLIGIBLE	0.86	0.6	698	5.0	7.2	4.2	12.4	1058.0	7.07	2.5	19.2	0.16	28.6	0.3	0.90	0.24	5.50	21.9
SHALE	279 - 292	1.88	0.07	6.0	NEGLIGIBLE	0.43	0.3	264	4.0	8.1	4.4	11.8	1478.0	8.70	11.0	37.0	0.25	20.6	0.5	0.89	0.25	5.10	48.0
SANDSTONE	292 - 302	0.53	0.02	7.4	NEGLIGIBLE	0.60	0.7	554	3.0	6.2	3.3	13.2	1336.0	13.91	8.7	19.5	0.03	19.6	0.5	0.70	0.03	6.60	35.1
SANDSTONE	302 - 320	2.25	0.01	13.0	NEGLIGIBLE	0.43	0.6	663	2.0	5.8	3.3	11.4	1050.0	12.39	17.4	48.0	0.09	9.9	0.4	0.63	0.26	7.70	31.1
SANDSTONE/SILTSTONE	320 - 340	2.22	<0.01	10.9	TRACE	0.43	2.3	474	3.0	5.6	4.4	7.1	593.0	14.35	19.5	47.0	0.10	17.7	0.4	0.70	0.32	3.50	29.5
SANDSTONE/SILTSTONE	340 - 356	1.38	0.03	9.7	NEGLIGIBLE	0.68	3.5	2130	3.0	5.9	4.3	10.8	576.0	19.35	8.0	23.8	0.13	26.2	0.6	0.76	0.67	2.20	34.1
SANDSTONE	356 - 370	1.63	0.01	8.2	NEGLIGIBLE	0.51	1.1	800	2.0	5.4	2.6	10.0	1034.0	9.02	1.8	11.1	0.15	13.2	0.4	0.74	0.26	5.10	25.5
SILTSTONE/SANDSTONE	370 - 399	1.00	0.03	6.2	NEGLIGIBLE	0.09	3.4	1600	3.0	6.3	3.4	16.4	580.0	15.87	4.3	24.0	0.11	18.5	0.3	1.00	0.49	2.80	26.2
SILTSTONE	399 - 421	0.66	0.05	11.1	3.1	0.34	0.7	1255	6.0	6.4	3.8	10.4	611.0	18.78	32.2	68.2	0.11	17.5	0.1	0.38	0.20	5.60	28.8
CONGLOMERATE	421 - 426	1.00	0.11	17.2	3.4	0.34	0.3	2550	7.0	6.3	4.1	21.5	1805.0	20.43	23.3	48.5	0.11	13.9	0.3	0.44	0.46	7.90	43.2
SILTSTONE	426 - 446	1.78	0.02	13.5	2.6	0.256	1.1	1125	3.0	5.0	3.7	5.8	435.0	20.00	53.9	64.0	0.06	13.3	0.5	0.88	0.42	5.10	37.0
SHALE	446 - 456	2.22	0.05	9.3	3.7	<0.05	0.4	1200	6.0	4.1	2.1	8.0	397.0	16.54	35.8	57.7	0.15	26.5	0.7	0.74	0.44	2.00	23.2
SHALE/SILTSTONE	456 - 466	2.16	<0.01	8.5	2.8	0.43	0.3	530	7.0	6.3	2.2	11.4	1080.0	6.74	23.7	45.0	0.30	31.5	0.7	0.35	0.24	7.20	29.9
SHALE/SILTSTONE	466 - 478	2.03	0.01	9.6	0.5	0.43	<0.1	1190	17.0	6.7	3.6	8.9	502.0	11.30	21.6	53.7	0.77	27.5	0.8	0.35	0.72	6.40	28.2
SHALE/SILTSTONE	479 - 488	1.63	<0.01	8.6	2.6	0.17	0.1	638	22.0	5.4	2.2	12.1	1460.0	15.26	15.2	76.9	0.06	19.9	0.5	0.76	0.49	7.90	38.0
SHALE/SANDSTONE	488 - 496	1.09	0.01	8.4	1.6	<0.05	0.6	938	4.0	4.7	2.5	21.0	1520.0	13.33	20.7	64.4	0.06	14.5	0.3	1.50	0.72	9.40	48.3

TABLE 4

NORMAL AND HAZARDOUS CONCENTRATIONS OF

MICRO NUTRIENTS AND TRACE ELEMENTS

GROUP	ELEMENT	NORMAL CONCENTRATION	HAZARDOUS LEVEL
MICRO NUTRIENTS	Cu	0.5 to 40 ppm Extractable	Above 40 ppm Extractable
	Zn	10 to 300 ppm (Total)	Above 10 ppm Extractable
	Mn	0.5 to 40 ppm Extract.	Above 40 ppm Extractable
	Fe	1.5 to 2% (Total)	No Potential Direct Hazard
TRACE ELEMENTS	Hg	0.1 to 0.5 ppm	Above 0.5 ppm Extractable
	Pb	15 to 70 ppm (Total)	1 to 5 ppm Extractable
	Cd	---	0.1 to 1 ppm Extractable
	Se	---	Above 1 ppm Extractable
	B	---	Above 2 to 3 ppm Extractab
	Mo	---	5 ppm (Total) Under Neutra to Alkaline pH Conditions
	Ni	---	Above 1 ppm Extractable

3. INTERPRETATION

3.1 Rate of Weathering

Degradation in the waste pile involves both physical and chemical weathering. Physical breakdown is an important factor governing the release of highly erodeable materials. It is also an important factor governing the rate of subsequent chemical weathering.

Physical breakdown of rock fragments buried in the waste pits is expected to take place slowly. Breakdown of material exposed to surface weathering was assessed as follows:

Shale	-	rapidly break down to clay soil upon exposure
Sandstone-Siltstone	-	1/3 will break down to silt and sand sized particles in one year
		1/3 will break down to smaller rock fragments and silt and sand sized particles in 5 years
		1/3 will resist break down for a long time.

Examination of 20 year old waste dumps in the area confirmed the above prediction. The surface was typically a stoney sandy clayey silt. Widespread breakdown to erodeable silt sizes was not evident. Rock fragments within the waste pile appeared to remain intact.

Chemical weathering within the waste pile will be related to minerology, temperature, type and amount of percolating groundwater and time. By design the amount of infiltrating water will be small. Thus the rate of chemical weathering is expected to be very slow.

3.2 Concentrations Present

Chemical make-up of the bedrock is related to lithology. The composition of the sandstone was quite uniform while that of the siltstone or shale was more variable.

Trace element concentrations were found to be quite uniform. This suggests that the trace elements are tied to the mineral lattice and are not free to migrate except under extreme weathering.

Normal concentrations were found for all elements except for manganese, lead and nickel. Concentrations of the latter elements are not severe and represent the upper limit that would be made available under sudden extreme weathering. With the slow rate of weathering anticipated, release of harmful concentrations is not expected.

3.3 Potential for Acid Mine Waste

The concentration of Sulphur is low. Consequently, there is little chance of extreme weathering creating acid mine waste. The potential for acid mine waste is further reduced by the presence of neutralizing carborate.

3.4 Potential Toxicity

The potential for weathering causing the release of toxic concentrations of any element is very low.

3.5 Revegetation Potential

Revegetation potential is indicated by the availability of nutrients, pH and sodium absorption ratio. The rock does not possess an abundance of nutrients but an ability to support vegetation without repeated fertilizing is indicated. This has been supported by field experience.

On the basis of sodium absorption ratio the potential for revegetation is greater in hangingwall sediments than it is in footwall material. Most mining activity will involve the hangingwall material.

3.6 Implication to Mining

No beds were found that should react adversely to weathering so it is concluded that weathering of material disturbed by mining will not have harmful side effects. Consequently, from a geotechnical point of view, mined material may be placed in waste dumps in any order convenient to the mining program.

4.0 CONCLUSIONS

A representative profile of materials in the proposed mining zone were sampled and analysed.

Physical weathering at surface is predicted to yield clayey soil that is not highly erodeable. Field observations support this prediction. Rock fragments within the waste pile will degrade slowly.

Chemical weathering is also expected to take place very slowly.

Most elements were found to be present in normal concentrations so there is little chance of weathering causing toxic concentrations of them to be released.

Acid mine water is not a problem here.

Mining can proceed without regard for placement priorities because of the uniform chemical make-up of the waste material.

The subject sampling program was necessary to indicate that there are no problems anticipated from weathering at this site. A similar testing program is advocated at each new mine site. However, detailed testing need only be carried out if adverse conditions are detected.

PAPER

-16-

The Distribution of Nutrients and Organic Matter in Native Mountain Grasslands and Reclaimed Areas in Southeastern B.C.

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ABSTRACT

This is an interim report on a study examining the plant community nutrient cycles of reclaimed mined lands. The study's purpose is to assess the nutrient self-sufficiency of five-year-old reclaimed areas in montane and subalpine environments. Adjacent, undisturbed native grasslands were also studied for comparative purposes.

Paired plots were established on the four community types and shoot, root, detritus and soil levels of nitrogen, phosphorus and potassium were monitored over the course of a year. Organic matter distribution among shoot, root and detritus compartments are presented from August, 1976 to June, 1977. Shoot, root, detritus and soil levels of nutrients in August and October, 1976 are also presented.

Shoot, root and detritus levels were highest on the montane native grassland with the subalpine native area following. While the reclaimed areas were occasionally higher in shoot mass, root and detritus levels were far below those on the native areas. Root mass was higher on the montane than in the subalpine reclaimed area.

Higher nutrient levels in most compartments were found in the native areas indicating greater nutrient accumulation and storage, though exchange rates have not been calculated yet. Though the overburden materials on the reclaimed areas are poor in some nutrients the reclaimed areas contain more nitrogen and phosphorus than has been added artificially. This indicates that at least some overburden shales and coal contain significant levels of these nutrients.

INTRODUCTION

Reclamation practices in southeastern British Columbia usually include resloping, seeding with agronomic grasses and legumes and annual maintenence fertilization, usually of 200 kg (13-16-10) ha^{-1}. Many areas thus treated appear quite vigorous five years after initial treatment. We have, however, virtually no idea how near these reclamation plant communities are to nutrient self-sufficiency.

Reclamation is often defined implicitly or explicitly as a process that leads to the establishment of a self-sustaining vegetation cover on disturbed lands. The definition begs two questions: What is self-sustaining vegetation cover and how can we tell when vegetation is self-sufficient? Such a plant community must contain species able to complete their life-cycles on a given site.

It must also be able to capture and recycle nutrients and energy at a rate capable of maintaining production at acceptable levels. Observations of seedling production and survival as well as mature plant mortality should indicate whether the community is restocking itself at an adequate rate. However, the question of nutrient stability is more difficult to answer.

Nutrient dynamics in ecosystems has been the subject of considerable study by plant ecologists. Many such studies were reviewed by Rodin and Basilevich (1965). Ideally, these studies dissect the plant community into discrete compartments through which nutrient flow or tie-up can be measured. A grassland might be divided into shoot, root, detritus and soil compartments for the sake of simplicity. Given these parameters of interest, such a study should quantify both the standing crops (mass per unit area) and exchange rates (change per unit area per unit time) among compartments. Thus, nutrient cycling studies not only indicate the nutrient pool upon which the plant can draw and its location, but the rate at which exchange processes (plant uptake, decomposition and mineralization) occur. Naturally, if nutrient capital is high but exchange rates low, production will also be low.

This study was designed to answer questions concerning nutrient self-sufficiency of reclaimed areas. Consequently, the nutrient cycles of both reclaimed and undisturbed native grasslands at montane (1600 m el) and subalpine (2200 m el) environments were studied. It should indicate whether the native areas are more nutrient stable than the reclaimed areas and whether montane areas are more stable than the subalpine areas. Sampling began in August, 1976 and will be completed by October, 1977. The experiment is being conducted on Kaiser Resources Ltd. property near Sparwood, B.C. Thus, midway through the experiment, these data are preliminary and will be discussed only in terms of standing crop as exchange rates will only be calculated at the end of the experiment.

METHODS

In August, 1976 highly productive reclaimed areas at montane (1600 m el) and subalpine (2100 m el) locations were selected along with adjacent undisturbed native grasslands. Paired plots 30.5 m x 7.6 m separated by a 4.5 m buffer strip were established on each of four areas. Sampling within plots consisted of fifteen 30 cm x 15 cm rectangles in which detritus and shoot material were clipped. Thirty root samples per plot were obtained by cores which were separated in the laboratory. Three soil samples consisting of clusters of four were taken on each plot and analyzed separately. Each shoot, detritus and root sample was weighed to obtain an estimate of standing crop within each compartment. Composite samples of each compartment were analyzed for major nutrients. All soil and plant analyses were conducted by Dr. L.M. Lavkulich's lab in UBC's Soil Science Department. Thus far samples have been taken in August and October, 1976 and in May and June, 1977.

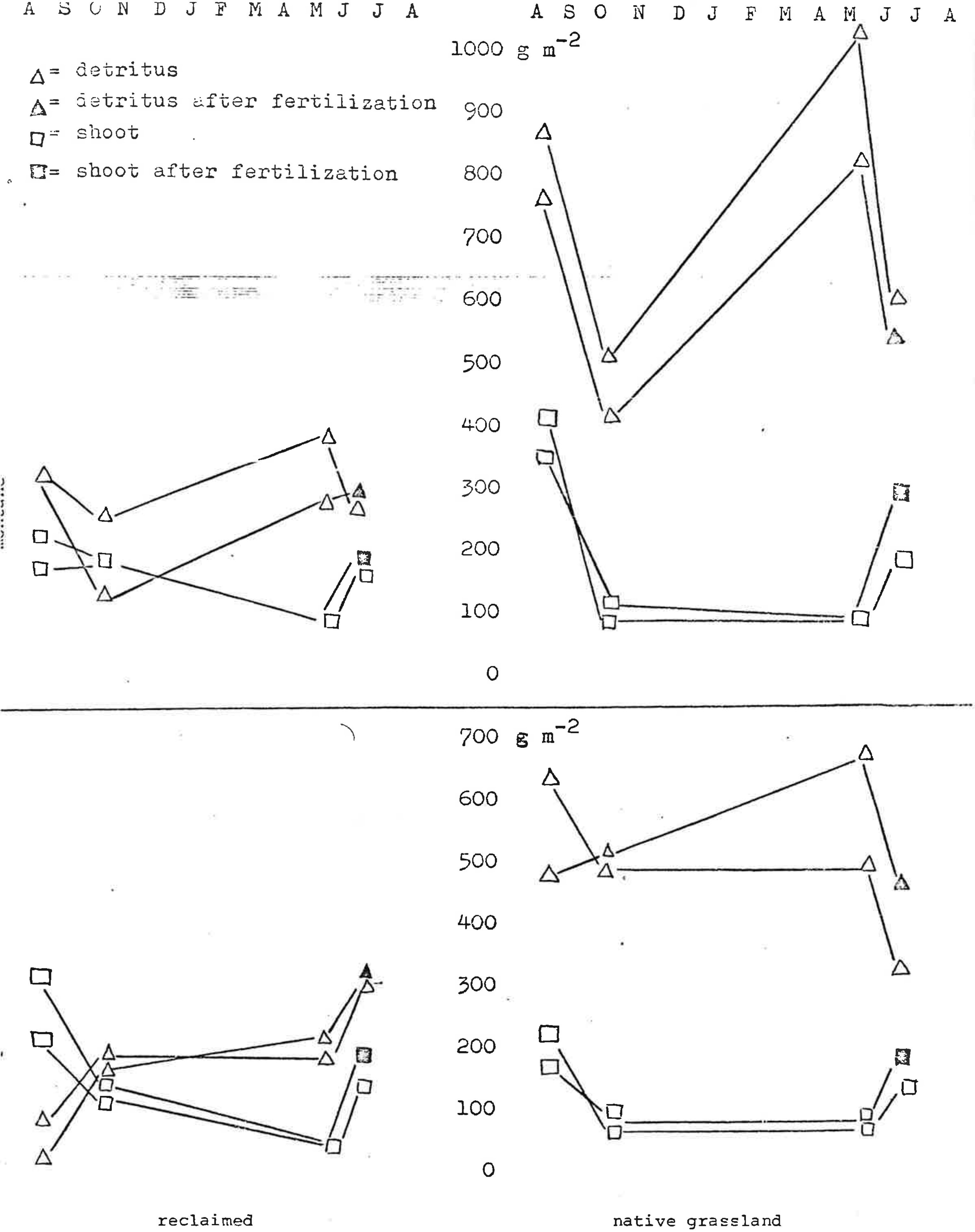
On June 3, 1977 one of the paired plots in each of the four test areas was treated with 1000 kg (13-16-10) ha^{-1} fertilizer while the other of the pair remained unfertilized. Monitoring of the plots should continue until October, 1977 on a roughly monthly schedule.

RESULTS AND DISCUSSION

Thus far, organic matter data are available from August, 1976 to June, 1977 (Figure 1). In both montane and subalpine native grasslands, shoot mass reaches a yearly minimum in October which continues until May. Rapid growth, appraching August levels, occurred by late June. In both montane and subalpine native grasslands fertilization resulted in higher shoot yields; in the montane area yield was doubled over the unfertilized paired plot. The montane native area, while only slightly more productive in October and May than the subalpine area, was nearly twice as productive in August and June than the subalpine native grassland.

Shoot levels on both montane and subalpine reclaimed areas decreased from August to October. However, rather than remaining constant until May like the native areas, the reclaimed areas both lost a further 50% of their shoot mass by late spring. This data suggests that the reclamation species were somewhat out of phase with the local climate, entering the winter period with more shoot mass than could be supported. Many of the species were still flowering

Figure 1. The distribution of oven dry organic matter (g m^{-2}) in shoot and detritus compartments, the data represent levels in paired plots. Where the lines join to form one character the values for paired plots are the same. The darkened characters represent the fertilized plot after fertilization.



A S O N D J F M A M J J A
△= detritus
△= detritus after fertilization
□= shoot
□= shoot after fertilization
1000 g m-2
900
800
700
600
500
400
300
200
100
0
700 g m-2
600
500
400
300
200
100
0
reclaimed
native grassland

in October and some showed frost damage. Nonetheless, both fertilized and non-fertilized reclaimed areas returned to near their previous August levels by late June although the fertilized plots were more productive in both montane and subalpine reclaimed areas.

Detritus levels on the montane native area decreased from nearly 800 gm^{-2} in August to 475 gm^{-2} in October. This drop, coinciding with drops in shoot mass over the same period suggests an interval of very rapid decomposition. Surprisingly, by May detritus levels had increased to near August levels. This may in part be explained by the great number of elk pellets found on the site in May. Since the area is very heavily used as winter range these pellets may constitute a significant import into the system. Nonetheless, with the onset of the growing season mineralization again proceeds at a higher rate than detritus accumulation resulting in a sharp drop in detritus levels from May to June. Though detrital standing crop values were lower in the subalpine native area, the pattern appeared similar to that in the montane native grassland. Also, fertilization appears to have had no consistent effect on detritus levels.

Detritus levels on the montane reclaimed area, like the native areas, declined from August to October, rose by late May and in the unfertilized plot dropped as substantial shoot growth began. The fertilized plot showed no such decrease from May to June. In contrast, detritus levels in the subalpine reclaimed area were very low in August, increased toward October, remained nearly constant over winter and rose sharply with the onset of substantial plant growth. This seeming anomaly may be the result of death of early plant growth in spring where frost and drought could damage species that weren't fully adapted to these conditions. The low detritus levels in August, 1976 were due to the very low production on the site in 1975. Thus, interpretation of these data must acknowledge the highly dynamic nature of these young systems.

As with shoot mass, root mass was highest at the beginning of the study on the montane native grassland at 1600 gm^{-2}. The subalpine native area at 1200 gm^{-2} was second with the montane and subalpine reclaimed areas at 500 and 100 gm^{-2} respectively. Except for the subalpine reclaimed areas, all root masses dropped from August to October. The montane native grassland remained at the same root level till May then rose sharply to 3200 gm^{-2} by June. The subalpine native grassland root mass increased by May to about 2200 gm^{-2} and continued to increase to 3400 gm^{-2} by June. The montane reclaimed area dropped to 100 gm^{-2} by October and by May rose to about 400 gm^{-2}. This rose to

600 gm^{-2} in June. The subalpine reclaimed area root mass rose from August to October and remained at about 200 gm^{-2} until May. By late June root mass increased to about 300 gm^{-2}.

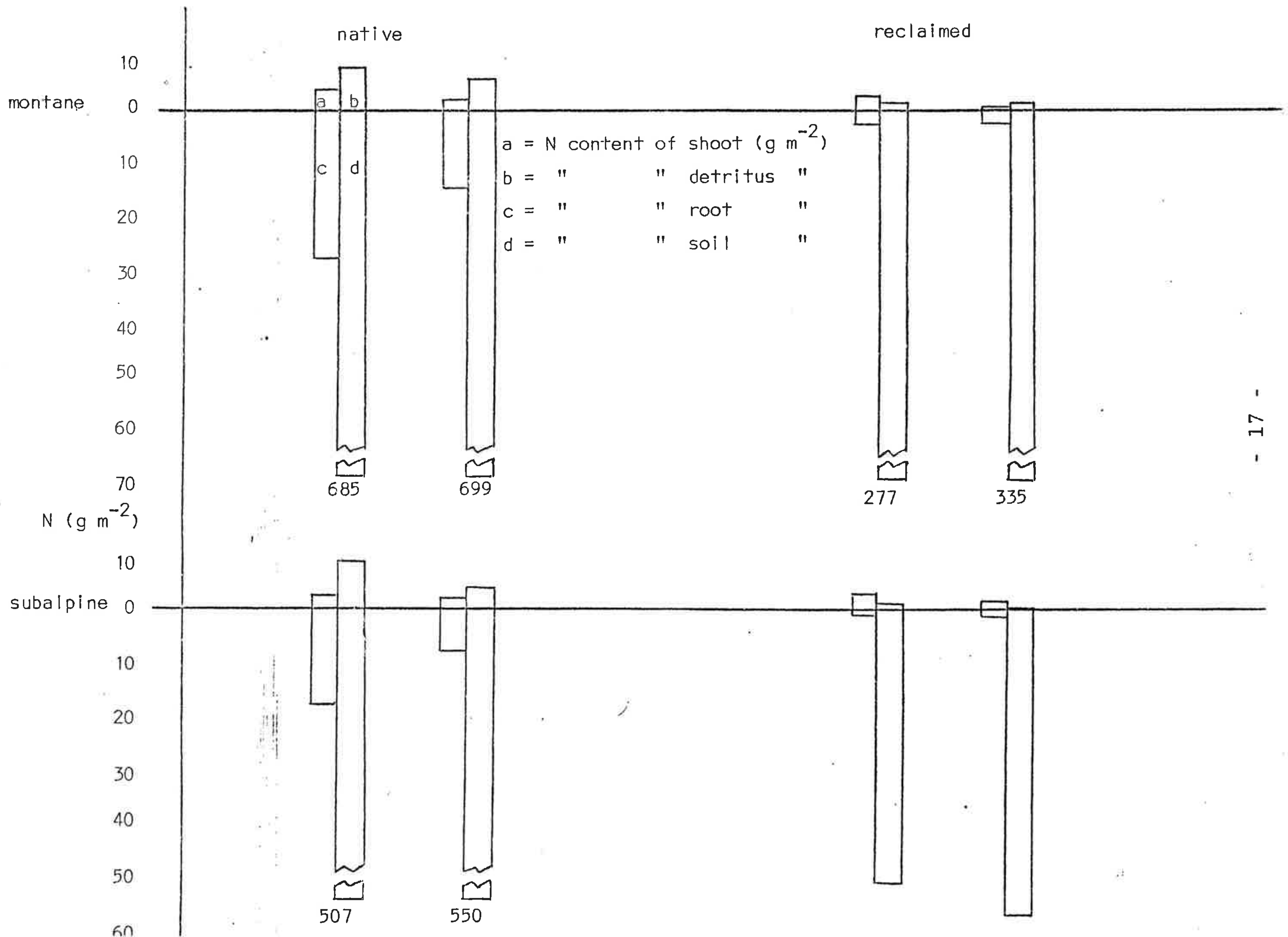
The large difference between native and reclaimed root masses is significant in that the root mass represents a large carbohydrate and nutrient reserve which is to some extent available for translocation to the shoot mass in early spring. Obviously, a greater storage facility of this sort is available to the native communities. Care must be taken in interpreting the data as the reclaimed areas, as young communities, are probably still in the process of developing a root system. The continuous rise in the root mass of the subalpine reclaimed area, resulting from absence of all die-off is probably due to the youth of the root system. The data will indicate by October, 1977 whether the reclaimed areas are showing a net increase or decrease over the course of a year.

Thus far fertilization or the absence of fertilization had no effect on the root masses of any of the studied plant communities.

Thus far chemical analysis data are available only for the August and October, 1976 samples. However, the data indicate system totals and distribution of nutrients within shoot, root, detritus and soil compartments. From this type of data exchange rates, accumulations and losses will be calculated for the compartments of each treatment. This should suggest whether, for example, nitrogen mineralization and intake proceeds at a rate sufficient to maintain an acceptable shoot cover on the reclaimed areas without annual fertilization. Shoot, root detritus and soil samples have been analysed for N, P, K, Ca and Mg. Except for nitrogen, soil data represent available nutrients. For the sake of brevity, only N, P and K data are presented in this paper. Also, only the left paired plot is shown for each site.

In both native and reclaimed areas the bulk of system nitrogen is in the soil compartments (Figure 2). However, the rapidly cycling portion of the nitrogen pool is more likely in the shoot, root, detritus and only a fraction of the soil compartment. The montane native community had the greatest pool of nitrogen with most in the soil followed by a large root pool, a smaller detritus pool and lastly a relatively small shoot pool. This pattern was consistent in both montane and subalpine native areas in August and October, although over this period the organic pools decreased while the soil pool increased. The reclaimed areas differed in having lower levels in all compartments except shoot in August.

Figure 2. The distribution of nitrogen in shoot, detritus, root and soil compartments of montane and subalpine native grasslands and reclaimed areas, soil nitrogen is represented as the Kjeldahl-derived total.



native
reclaimed
montane
subalpine
N (g m^{-2})
10
0
10
20
30
40
50
60
70
a = N content of shoot (g m^{-2})
b = " " detritus "
c = " " root "
d = " " soil "
685
699
277
335
507
550

Phosphorus levels were again highest in the montane native area (Figure 3). Also, like nitrogen, most phosphorus available to the plant community was in the soil, followed by root, detritus and finally shoot. Though total levels are lower in the subalpine native area the same distribution pattern is evident both in August and October. Phosphorus capital was lower in both reclaimed areas. Though its significance is as yet unknown, the distribution of phosphorus in the montane reclaimed area approximates that in the native communities.

System potassium levels, like those of nitrogen and phosphorus, were highest in the most productive site: the montane native grassland (Figure 4). The subalpine native area followed in potassium capital with both reclaimed areas at comparitively low levels. As with the two macronutrients previously mentioned, most of the systems's potassium was found in the soil. The low soil values for available potassium in the reclaimed areas may be due to low cation exchange capacity as well as low initial content in the overburden. The distribution of potassium is different from that of nitrogen and phosphorus in that the shoots constitute a larger pool of potassium than either root or detritus.

Figure 3. The distribution of phosphorus in shoot, detritus, root and soil compartments of montane and subalpine native grasslands and reclaimed areas, the soil phosphorus levels represent available phosphorus.

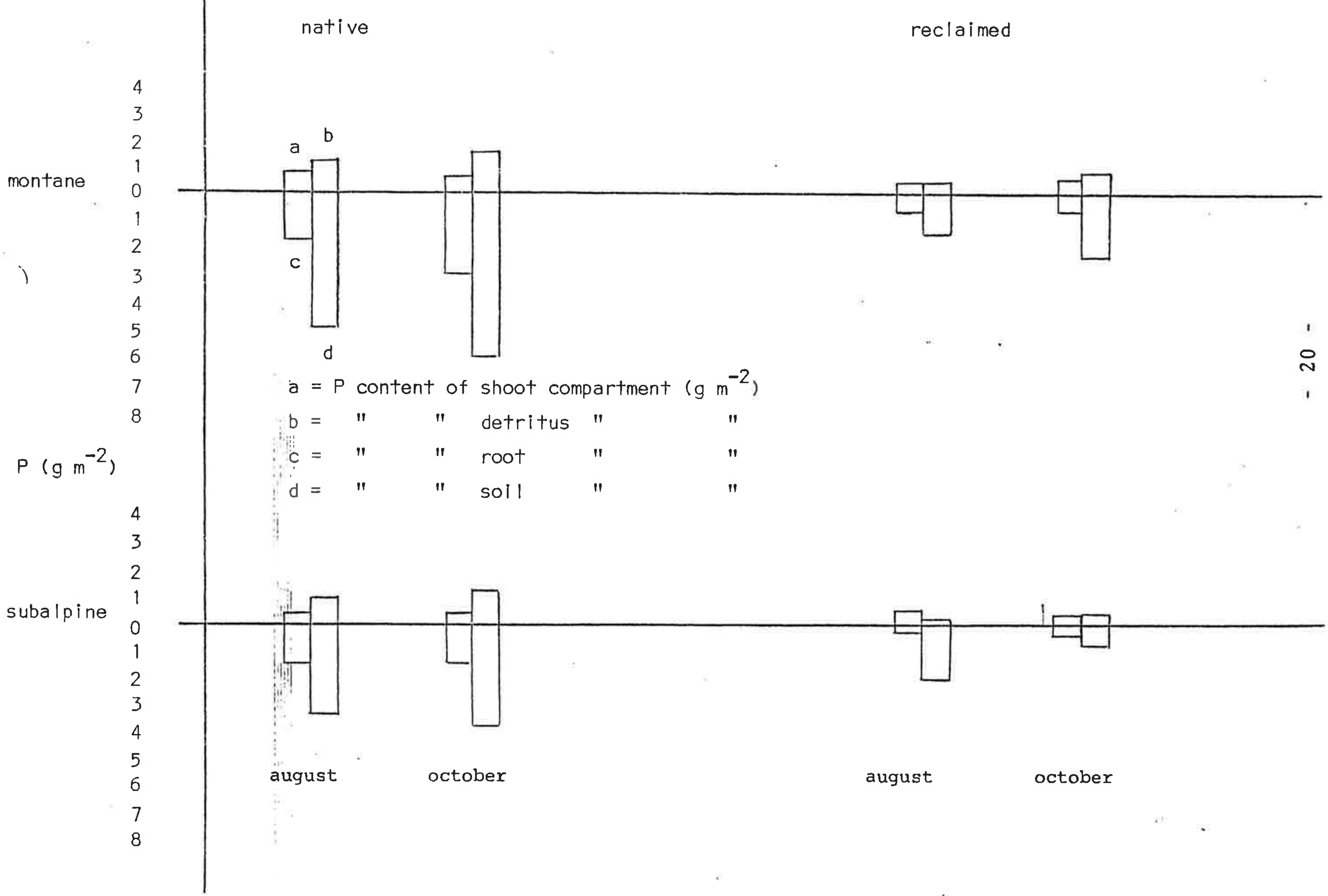
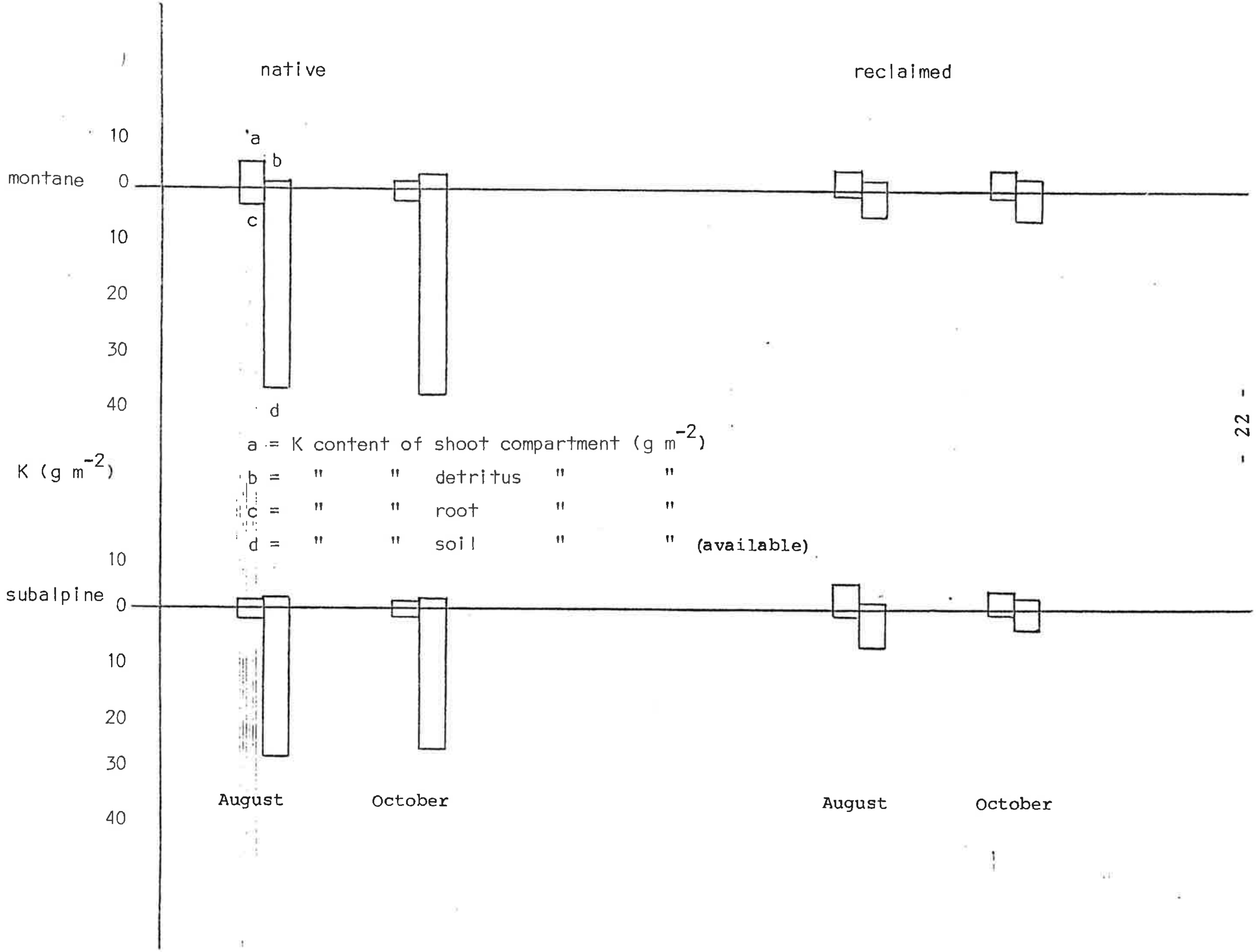

native
reclaimed
montane
subalpine
P (g m^{-2})
4 3 2 1 0 1 2 3 4 5 6 7 8
a
b
c
d
a = P content of shoot compartment (g m^{-2})
b = " " detritus " "
c = " " root " "
d = " " soil " "
august
october
august
october

Figure 4. The distribution of potassium in shoot, detritus, root and soil compartments of montane and subalpine native grasslands and reclaimed areas, soil potassium levels represent exchangeable potassium.



native
reclaimed
montane
subalpine
K (g m^-2)
10
0
10
20
30
40
a
b
c
d
a = K content of shoot compartment (g m^-2)
b = " " detritus " "
c = " " root " "
d = " " soil " " (available)
August
October
August
October

CONCLUSIONS

Conclusions drawn in an interim report require a great deal of circumspection. Consequently, I'll keep my conclusions in this paper to a minimum.

In terms of shoot, root and detritus, the montane native grasslands are by far the most productive. The subalpine native grasslands are next with the montane and subalpine reclaimed areas following. This order coincides with shoot, root, detritus and soil levels of N, P and K. While fertilized plots in all areas were higher in shoot production one month after treatment no such effect on root production or detritus levels was evident.

As insufficient chemical data is as yet available it is not possible to assess the different plant communities in terms of rate of nutrient release and uptake. However, the data indicate higher levels of N, P and K in most compartments in the native areas indicating greater accumulation and storage of nutrients in these areas. Again it must be noted that the reclaimed areas are young and were initiated on nutrient-poor overburden shales and coal. Though these overburden materials are poor in nutrients, both nitrogen and phosphorus levels in reclaimed areas were higher than the total fertilizer inputs over their five-year lifespan. However, potassium levels in reclaimed areas approximate artificial input levels. This indicates considerable nitrogen and phosphorus levels in at least some of the overburden materials, though their availability and release rates are not known.

REFERENCES CITED

Rodin, L.E. and N.I. Bazilevich. 1965. Production and mineral cycling in terrestrial vegetation. Trans. to English by G.E. Fogg. 1967. Oliver and Boyd, Edinburgh, U.K. 288pp.

PAPER

-17-

Paper No. 17

Author(s): D.M. Galbraith

Title of Paper: "Systems Inventory of Surficial Disturbance. Peace River Coal Block, B.C."

ABSTRACT

The Peace River Coal Block in B.C. extends a distance of 150 miles from the Williston reservoir to the Alberta border. Approximately seven hundred and fifty Coal Licences are involved, each one mile square. Activity occurs both within the Licences - roads, drill sites, trenches, adits; and outside (access via Chetwynd, Dawson Creek and Grande Prairie). This disturbance requires identification and inventorying in a systemized manner for purposes of bonding, approval of proposed work under Section 8 of the Coal Mines Regulation Act, for field inspection of work and reclamation, and for design of exploration and development protection and reclamation programs.

The scope and detail of the requirement can only satisfactorily be met through the use of aerial photography. The system developed has eight basic steps:

1) Procurement of airphotos of suitable date and quality.
2) Incorporation into an airphoto mosaic.
3) Marking of boundaries of Coal Licences.
4) Identification of nature of disturbance, referencing on an inventory sheet by Licence.
5) Measurement of identified disturbed area by digitized planimeter.
6) Presentation of individual licences and inventory sheets in field format.
7) Field checking and discussions with company based on format.

8) Summarization of critical data in computer program for future retrieval.

The first seven steps will have been completed in the areas of major interest in the summer of 1977, and the details of step 8 will be determined.

AIRPHOTO INVENTORY OF SURFACE DISTURBANCE

INTRODUCTION

MY TALK TODAY CONCERNS THE USE OF AERIAL PHOTOGRAPHY IN THE RECLAMATION OF SURFACE DISTURBANCE RELATED TO COAL EXPLORATION IN THE NORTHEAST COAL BLOCK OF B.C.

ACCESS TO THE COAL BLOCK IS VIA CHETWYND AND DAWSON CREEK, BRITISH COLUMBIA, OR BEAVERLODGE, ALBERTA. The N. E. COAL BLOCK CONTAINS 721 COAL LICENSES TYPICALLY OF 1 SQ. MILE EXTENT, OUR PROGRAM INCLUDED 212 LICENCES IN THE AREAS OF MAJOR DISTURBANCE.

THE COAL BEARING FORMATIONS OF THE PEACE RIVER BLOCK OCCUR IN THE ROCKY MOUNTAIN FOOTHILLS, WHICH IS TYPIFIED NEAR THE ALBERTA BORDER BY ALPINE COUNTRY AND NEAR THE WILLISTON RESERVOIR BY FOREST.

SURFACE DISTURBANCE OCCURS THROUGHOUT.

THE ROLE OF AERIAL PHOTOGRAPHY

IN THE ADMINISTRATION OF THE LEGISLATION IT IS A MAJOR TASK JUST TO KEEP TRACK OF ACTIVITY OVER SUCH A WIDE AREA. THE OBJECT OF THE LEGISLATION IS THE PLANNING OF WORK AND ACHIEVEMENT OF RECLAMATION IN SUCH A MANNER THAT THE ENVIRONMENT IS PROTECTED. IF WE WORK BACKWARD FROM THIS OBJECTIVE TO WHERE WE ARE TODAY, WE CAN BETTER DEFINE THE ROUTE WE MUST TRAVEL TO REACH THIS GOAL.

WE COULD REASON AS FOLLOWS: THE MAJOR REQUIREMENT FOR RECLAMATION IS SITE PREPARATION; SITE PREP. REQUIRES OPERATIONAL PLANNING; OPERATIONAL PLANNING REQUIRES PROFESSIONAL DECISION MAKING; PROFESSIONAL DECISION MAKING REQUIRES A PLANNING MEDIA; THE BEST PLANNING MEDIA IS AERIAL PHOTOGRAPHY.

WE MIGHT REASON DIFFERENTLY. WE MIGHT ASSUME THAT THE OBJECTIVE WAS THE MINIMIZATION OF SURFACE DISTURBANCE. WE WOULD THEN CONCLUDE THAT THE MAJOR REQUIREMENT FOR THIS WOULD BE OPERATIONAL PLANNING. AGAIN WE WOULD RETURN TO THE NEED FOR

AERIAL PHOTOGRAPHY. ORGANIZATION OF AVAILABLE PHOTOGRAPHY

OUR USE OF AERIAL PHOTOGRAPHY WITHIN THE WIDE EXPANSE OF THE N.E. COAL BLOCK HAS REQUIRED ORGANIZATION AND USE OF SAME WITHIN A SYSTEM, AND THUS OF TITLE. AID PROGRAM (AERIAL INVENTORY OF DISTURBANCE) HAD A BETTER RING TO IT THAN AISD, HOWEVER THE MATERIAL WAS SLIGHTLY TAILORED TO FIT THE PURPOSES OF THIS CONFERENCE. THE STEPS IN OUR ORGANIZATION OF AIRPHOTOS, AND IN THEIR APPLICATION TO THE RECLAMATION OF SURFACE DISTURBANCE WERE AS FOLLOWS:

(SLIDE 9L)

CONSIDERING EACH OF THE STEPS SHOWN IN TURN:

(SLIDE 10L)

STEP 1. DOCUMENTATION OF USABLE AERIAL PHOTOGRAPHY.

ALTHOUGH COAL EXPLORATION LEASES EXTENDED ALMOST CONTINUOUSLY FROM THE PEACE RIVER RESERVOIR TO THE ALBERTA BORDER.

IT WAS FOUND THAT ONLY APPROXIMATELY ½ OF THIS AREA WAS COVERED BY AERIAL PHOTOGRAPHY. (LICENCES ARE SHOWN IN THIN LINE.)

BLACK AND WHITE PHOTOGRAPHY IS SHOWN IN HEAVY BLUE, COLOUR PHOTOGRAPHY IS SHOWN IN HEAVY RED.

STEP 2. THE ASSEMBLY OF UNCONTROLLED MOSAICS.

(SLIDE 13L)

THESE WERE PREPARED FROM USABLE PHOTOGRAPHY AT APPROX. 1:10,000 SCALE OF INTENSIVE DISTURBANCE, AND THEIR LOCATIONS ARE SHOWN IN GREEN.

LESS THAN ONE-QUARTER OF THE AVAILABLE COVERAGE WAS UTILIZED IN MOSAICS AS ILLUSTRATED IN THE NEXT SLIDE.

SOME MOSAIC SHEETS INDICATE COVERAGE IN AREAS WITHOUT PHOTOGRAPHY. THIS ILLUSTRATES THAT THIS SLIDE IS ALREADY OUTDATED.

STEP 3. THE MARKING OF LICENCE BOUNDARIES.

THESE WERE MARKED ON THE PREPARED MOSAICS USING AS CONTROL WATERCOURSE JUNCTIONS SHOWN ON THE 1:50,000 NTS MAPS.

STEP 4. PREPARATION OF PHOTOPOSITIVE MYLARS.

(SLIDE 19L)

STEP 5. IDENTIFICATION OF DISTURBANCES WITHIN INDIVIDUAL LICENCES.

(SLIDE 20L)

THOSE OF YOU WHO HAVE IDENTIFIED THAT SLIDE AS A DRILL PAD SHOULD KNOW THAT IT IS IN FACT AN OLD MILL SITE.

STEP 6. INDEXING OF INDIVIDUAL DISTURBANCES ON THE PREPARED MOSAICS.

(SLIDE 23L) (SLIDE 24R)

STEP 7. MEASUREMENT OF DISTURBED AREAS

(SLIDE 25L)

WITH THE USE OF A DIGITIZED ELECTRONIC PLANIMETER.

STEP 8. RECORDING OF DISTURBANCES

(SLIDE 28L)

ON INDIVIDUAL LICENCE INVENTORY SHEETS.

STEP 9. FIELD CHECKING OF THE CALCULATION OF DISTURBED AREAS FOR ACCURACY.

(SLIDE 32L)

FURTHER WORK

THE FURTHER STEPS WHICH WE ARE NOW WORKING ON INDLUCE:

10. SUMMARIZATION OF THE ABOVE DATA ELECTRONICALLY FOR INSTANT RECALL. APPLICATION WOULD BE TO BONDING IN PARTICULAR, AND PROGRAM MANAGEMENT IN GENERAL.

COST OF THE PROGRAM TO THE FIELD USE LEVEL (STEP 8) IS $10,800 AND IT IS ESTIMATED APPROXIMATELY 3/4 OF THE DISTURBANCE IN THE PEACE RIVER COAL BLOCK HAS BEEN INVENTORIED. FUNDING FOR THIS HAS BEEN PROVIDED BY THE ENVIRONMENT AND LAND USE COMMITTEE FOR THE NORTH EAST COAL BLOCK. THIS IS NOW A FEDERAL PROVINCIAL PROGRAM.

FINDINGS

WHAT DID WE FIND OUT? WELL, WITH RESPECT TO ITEM 1 - DOCUMENTATION OF USABLE AERIAL PHOTOGRAPHY WE DISCOVERED THAT MOST OF THE LICENCE AREAS WERE NOT COVERED BY PHOTOGRAPHY. ATTENTION OF THE AGENCIES RESPONSIBLE FOR THIS HAS IN THE PAST BEEN DIRECTED TO SETTLED AREAS AND RELATED TO AGRICULTURAL ACTIVITY. THE COMPANIES AND THE B.C. GOVERNMENT HAVE

AND IN THIS CURRENT YEAR IT IS BEING EXPANDED. FURTHER CO-ORDINATION OF COVERAGE IS REQUIRED. WE FOUND OUT THAT A SCALE OF 1:15,000 DOES NOT SHOW SUFFICIEN DETAIL AND 1:10,000 IS JUST RIGHT.

WE ALSO FOUND OUT THAT COLOUR WAS PREFERRED BY THE INTERPRETER FOR IDENTIFICATION BUT BLACK AND WHITE MADE THE MOST LEGIBLE CHRONAFLEX'S, FROM WHICH THE BLUEPRINTS WHICH WERE CARRIED INTO THE FIELD WERE MADE. WE HAVE SINCE FOUND OUT THAT YOU CAN HAVE YOUR CAKE AND EAT IT WITH RESPECT TO COLOUR AND BLACK AND WHITE. THAT PROCEDURE IS TO OBTAIN COLOUR NEGATIVES AT A SCALE OF 1:20,000. THEN SUBSEQUENTLY COLOUR PRINTS CAN BE MADE AT A SCALE OF 1:10,000. BLACK AND WHITE NEGATIVES MAY ALSO BE MADE DIRECTLY FROM THE COLOUR NEGATIVES, AND FROM THESE BLACK AND WHITE PHOTOGRAPHS CAN BE PRINTED FOR THE PREPARATION OF MOSAICS AND CHRONAFLEX'S. THE ADVANTAGES ARE THREE-FOLD:

1) PHOTOGRAPHIC COVERAGE AND FLYING IS REDUCED BY A FACTOR OF 4 CONSIDERABLY REDUCING COST.

2) BOTH B & W COLOUR PRESENTATION ARE POSSIBLE, WITHOUT REQUIRING SOPHISTICATED EXPENSIVE DOUBLE CAMERA SET-UP.

3) DISTORTION IS DECREASED BECAUSE OF THE HIGHER ELEVATION FLYING.

<u>WHAT DID WE LEARN WITH RESPECT TO APPLICATION OF THE SYSTEM</u>?

1) THE PHOTOGRAPHS OF THE LICENCES IN MOSAIC FORM LEND THEMSELVES WELL TO THE DETERMINATION OF FUNCTIONAL MAP UNITS KEYED TO VEGETATION. THESE MAY BE DEVELOPED FURTHER INTO SENSITIVITY ZONES WHICH HAS APPLICATION TO BOTH WORK AND RECLAMATION.
AND RECLAMATION.

2) THE FORMAT AVAILABLE TO THE FIELD CREW FOR LOCATION OF WORK AND ASSESSMENT OF RECLAMATION IS SUPERIOR TO THE MAP FORMAT. SPECIFIC ADVICE TO THE COMPANY AS TO FURTHER WORK REQUIRED CAN BE NOTED DIRECTLY ON THE PHOTO.

3) THE PHOTOGRAPHIC FORMAT IS TRANSMITTABLE FROM FIELD TO HEADQUARTERS, TO OTHER AGENCIES AND TO THE COMPANY AT ANY LEVEL NOTHING IS LOST OR CHANGED IN THE TELLING, AND ALL USE THE SAME DATA BASE.

4) A RATIONAL BASIS IS ESTABLISHED FOR CALCULATING AREAS FOR BONDING PURPOSES AND FOR UPDATING OF SAME. A DIRECT RELATIONSHIP IS ESTABLISHED BETWEEN A COMPANY'S PERFORMANCE IN THE FIELD, AND THE COSTS WHICH ARE ASSESSED.

GOVERNMENT

<u>WHAT DID WE LEARN REGARDING THE PRESENT STATUS OF RECLAMATION IN THE NORTH EAST COAL BLOCK?</u>

WE LEARNED THE FOLLOWING:

1) 83 OF THE 212 LICENCES INVENTORIED (ABOUT 40%) HAD NO EXPLORATION WORK DONE ON THEM.
2) TOTAL DISTURBANCE AMOUNTED TO 408.7 HA. FOR AN ANVERAGE OF 3.2 HA. PER WORKED LICENCE.
3) NON MINING RELATED DISTURBANCE TOTALLED 256 HA. (SIESMIC FOR GAS/OIL EXPLORATION AND FORESTRY).

4) THE PRELIMINARY CONCLUSION FROM MEASUREMENT OF THE TOTAL DISTURBANCE IS THAT IT IS OF THE SAME RELATIVE MAGNITUDE AS THE FIGURES SUPPLIED BY THE COMPANIES, ALTHOUGH WE HAVE NOT REACHED THE END OF OUR COMPARISON AS OF YET. THE BEST APPLICATION OF THE INVENTORY SYSTEM MAY THEREFORE PROVE TO BE IN THE ESTABLISHMENT OF A RATIONAL SYSTEM WHICH HAS THE FLEXIBILITY TO RELEASE BONDING WHEN SPECIFIC WORK IS DONE RATHER THAN USING IT AS A CHECK OF CALCULATIONS SUBMITTED BY **THE COMPANIES**.

THE OPPORUTNITY SHOULD NOT BE LOST TO MENTION TO YOU AT THE CONCLUSION THAT WE NOW HAVE AN ANNUAL MINE RECLAMATION AWARD IN B.C. THIS IS PRESENTED AT

(SLIDE 33)L

A RECLAMATION SYMPOSIUM WHICH IS SCHEDULED TO TAKE PLACE SOMETIME AROUND ST. PATRICK'S DAY.

(SLIDE 34R)

WE WOULD GUESS VERNON, B.C. MARCH 15 AND 16. LAST YEARS WINNER WAS KAISER RESOURCES LTD.

PAPER

-18-

Paper No. 18

Author(s): D. Walker, R.S. Sadasivaiah and J. Weijer

Title of Paper: "The Selection and Utilization of Native Grasses for Reclamation in the Rocky Mountains of Alberta"

ABSTRACT

Disturbed areas in the mountain regions of Alberta often present an environment too harsh for commercially available farm and lawn grasses. Porous soil is very dry and infertile and domesticated grasses often require constant maintenance through periodic fertilizer applications. Native species of grasses, adapted to the prevailing climatic and soil conditions through many thousands of years of selection could be part of a solution to this difficult reclamation problem.

The purpose of this project is to collect, increase and maintain a seed source of grasses native to the Rocky Mountain region of Alberta. And, from this collection, to select the most promising species for reclamation and wildlife range improvement and to improve these species genetically to the point that economical agricultural production is feasible.

Data is presented from a large transplant study. Native grass ecotypes appear to be more widely adapted than previously thought. Seedling establishment is one of the biggest problems confronting the utilization of native grasses. Transplanting container grown native grass plants can be a very effective method of rapidly establishing a ground cover on drastically disturbed areas with extreme climatic conditions.

There are many problems prohibiting the large scale agricultural production of native grass seed. Seed shattering, low yields, hairs and awns, intermittent flowering, low fertility and uneven ripening are factors which will make native grasses expensive to produce. Some of the problems can be solved through genetic improvement and some through agricultural engineering technology.

THE SELECTION AND UTILIZATION OF NATIVE GRASSES FOR RECLAMATION IN THE ROCKY MOUNTAINS OF ALBERTA

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INTRODUCTION

Native grass species have adapted to the prevailing climatic and soil conditions of Alberta's Rocky Mountains through many years of natural selection. It is generally accepted that disturbed areas in the mountain regions often present an environment too harsh for commercially available farm grasses. In addition, the farm grasses require constant maintenance through repeated fertilizer applications which adds to the cost of a reclamation program. In view of these points the native grasses are receiving increasing attention in reclamation and range land improvement programs not only in Canada but also in many parts of the world.

We recently initiated our grass project with the following objectives: 1) to collect, increase and maintain a seed source of grass species native to the Rocky Mountain regions of Alberta, and 2) to select the most promising species for reclamation and wildlife range improvement and improve these species genetically to the point that economical agricultural production is feasible.

The concept of applying principles of agriculture and genetics to plants for reclamation is not new. For example, the Soil Conservation Service (a U.S. Department of Agriculture agency encompassing the six Pacific Northwest and Great Basin States) has been in operation for over forty years. The five SCS Plant Materials Centers have three functions: 1) to assemble, evaluate, select and increase grasses and legumes for use in soil and water conservation; 2) to determine reliable cultural and management methods for their use; and 3) to get proved materials into production by farmers, ranchers and commercial growers (Hafenrichter, 1968). They have screened more than 15,000 accessions of plants and produced over forty licensed varieties. By applying the most advanced techniques of agricultural practices and plant genetics, we hope, on a modest scale, to provide the same services as the SCS for Alberta.

Alberta Fish and Wildlife would like to use native grasses to improve the winter ranges of Elk and Bighorn Sheep. During the years of heavy snowfall, wild ungulates are restricted to grazing areas free of snow. These snow-free areas of the province are steep (up to 40°), south facing and wind-swept and present a very harsh environment for vegetation. Reseeding with drought resistant and winter hardy strains of native grass species is a recommended method of improving deteriorated ranges (Cornelius, 1946; Stefferud, 1948).

Parks Canada and Alberta Forest Service are interested in native grasses for alpine and sub-alpine reclamation studies. Porous soil is very dry and infertile and the use of native grasses could be a part of the solution to the reclamation of these disturbed areas.

There appears to be a widespread belief that native plants are intimately adapted to their environments and that their removal to other locales will be unsuccessful. However, the exact narrowness of such adaptability has not been well defined. The preliminary experiments described in this paper were performed to try to answer the very basic question of whether there are any ecological barriers which would limit the movement and utilization of native grass species within the Rocky Mountain regions of Alberta.

MATERIALS AND METHODS

Approximately 1500 specimens representing 25 native grass species were collected from more than 60 regions of Alberta's Rockies and transplanted to experimental plots at Ellerslie during 1974-76. Mortality rate was less than 1 percent.

Details concerning collection, planting techniques, procedures used for selection, photo-periodic studies and mountain test sites have been described in our previous reports (Walker and Weijer, 1974, 1975; Walker, Weijer and Sadasivaiah, 1976). Spikes from individual plants were harvested as and when they matured to study the variability with regard to number of productive tillers, seed yield and harvest date. This data was recorded for each plant. The number of plants studied in various species and accessions varied depending on the availability of the material. Results presented in this paper were collected on plants grown in growth chambers and field conditions at Ellerslie during 1974-76.

RESULTS

A. SELECTION PROGRAM

The plant species collected from their natural habitats showing varying degrees of genetic variability for many characteristics. Species and strains of species are being selected on the following criteria:

1. Wide adaptability: It would be a great advantage to have one variety of each species which could grow in all locales.
2. High seed production: To make seed production economical, plants showing above average yield should be selected.
3. High forage value: Strains exhibiting higher winter forage value for wildlife are selected for the Eastern slopes of the Rockies where the wildlife range has been decreasing.
4. Low seed shattering and even ripening: Native grasses depend on wind for seed dissemination. To make seed production economically feasible it is important to select plants which retain their seeds until harvesting has been completed.
5. Large seed size: There is vast variability between plants of a species in the size of their seeds. Larger seeds contribute significantly to successful seedling establishment (Youngner, 1972, Ch. 7).
6. Low biomass production: In some applications it appears desirable to use species which will not create a fire hazard or attract wildlife.
7. Disease free varieties: Plants which exhibit resistance to the various grass pathogens are being selected.

B. PHOTOPERIOD STUDIES IN GROWTH CHAMBERS

Since 1974 the various grass species in our collection have been grown in growth chambers in the Biological Sciences Building at the University of Alberta. In order to induce flowering in plants which has already produced have seeds, the following four pre-treatments were applied to potted plants. 1) Six weeks of 12 hour days plus 4 weeks at 4°C in total darkness. 2) Six weeks of 12 hour days. 3) Six weeks of 12 hour days plus 4 weeks at below 0°C (plants burried in snow). 4) Four weeks at 4°C and total darkness.

After pre-treatment, plants were returned to growth chambers with either 12 or 16 hour daylight periods. To induce flowering, all grasses used in our study required only the 4 week at 4°C total darkness treatment. Sixteen hour day growth period vs. 12 hour days appeared to make no difference to seed production in alpine and sub-alpine grasses.

C. PHOTOPERIODIC STUDIES IN THE FIELD

Data on the growth and maturity habits of approximately 1500 plants representing 29 species (collected from different geographical areas) grown in Edmonton are given in Table 1. Variations in the number of days to ripen seeds can be divided into three types.

1. Intra-plant variations: Some species such as Stipa columbiana and Phleum alpinum have an indeterminant tillering habit in which seed heads ripen one at a time throughout the growing season. This suggests that there is no single day on which the majority of seeds may be harvested and the only solution to this problem, though uneconomical, is a continuous type of harvest. The design of such a harvester is being attempted and is discussed elsewhere.

   Most other native species have a less severe type of indeterminant tillering habit in which the heads may ripen for a period of a few days to several weeks. This trait varies greatly from plant to plant and presents an opportunity for improvement of the agronomic quality of the species. Plants which exhibit a "tight" harvest period could be grouped with other members of their species which have a similar growing season. Thus the seed loss due to shattering is minimized and seed quality is not reduced by the presence of unripe seed. Data on intra-plant variability is not presented because of the large number of plants sampled.
2. Inter-plant variations within a geographical area: As can be seen from the data presented in Table 1, some species like Poa alpina and Agrostis scabra give two crops in a single growing season. The other species show a great deal of variation within a geographical area with respect to the number of days required to harvest.
3. Inter-geographical variations: With the exception of a very few cases, the growing season seems remarkably similar for all species collected from different regions of the province when they are grown in Edmonton. The variations are certainly no greater than those found within a geographical area.

D. MOUNTAIN TRANSPLANTS

In 1975 a program of field testing native grass species was begun in order to select the most promising species and strains for different climatic and soil conditions. To eliminate the variables of seedling establishment (seeding rate, mulches, etc.) seeds were germinated in growth chambers, transplanted to containers (2·5 cu in. Spencer-Lemaine seedling containers in 1976) and planted in mountain test sites in July. Sixteen plants of each species were spaced 25 cm apart in a one square meter plot. Soil amendments of any kind were not used. Two parameters were monitored biannually in the following years:

plant survival and ability to produce seed heads. Such characters as height, percent cover and vigour were not recorded because the species used were not of one genotype.

The results of transplants in mountain test sites are presented in Table 3. The survival of all species planted in different test sites was remarkably high and no statistically significant differences between species and sites were observed. The high survival rate observed in these studies clearly suggests that the seedling establishment is the most important problem in the successful utilization of native species. Most sites selected were either devoid or sparsely populated with native pioneer plants and the ease with which the transplanted grasses survived shows that the lack of vegetation could be due to seedling mortality. Other reasons for lack of vegetation on the disturbed sites are lack of seed source and infertile soil. Observations of these plots in subsequent years should give a better indication of how well native species can survive in infertile soils.

Transplanting container grown grass seedlings was found to be a very effective method of obtaining immediate cover on drastically disturbed sites with extreme climatic conditions.

DISCUSSION

The results obtained in this study, though not conclusive, do seem to suggest that populations of native grass species collected from different geographical regions of Alberta's Rocky Mountains are similar with regard to photoperiodic responses. All grass species used in the study flowered after four weeks of treatment at 4°C in total darkness. Following the treatment, the alpine and sub-alpine species grown under 12 and 16 hours day length periods did not show any marked difference in seed production. In contrast to this, Olmsted (University of Chicago) observed that the prairie grass (Bouteloua curtipendula) collected from Canada required longer days than those from Texas (quoted by Billings, 1970). Similarly, Hodgson (1966) reported photoperiodic response for flowering in Alaskan grasses. It is probable that alpine environments have such short growing seasons and widely variable growing conditions (shading from mountains, late and early blizzards, snowhollows, etc.) that a photoperiodic response for flowering is a luxury enjoyed by plants occupying less rigorous and more predictable environments. It appears that temperature is the main limiting environmental factor for flowering.

In the 1920's Gote Turesson of Sweden began some studies, which are now considered to be classic experiments, using the technique of transplanting plant material to uniform environments. He found that local populations were adapted to a given type of environment and possessed similar adaptive characteristics. Gote Turesson used the term ecotype to describe such locally and similarly adapted populations. While each local population within an ecotype varies somewhat within and between local populations, they have greater similarities to each other than they do to populations from other ecotypes of the same species. Although the results of our transplant studies are too premature to base definite conclusions there does appear to be a trend suggesting that plants from different locales can be moved successfully within the mountain regions of Alberta. If this trend continues in subsequent years of plot observation it would then appear that the grass species found in different locales of Alberta's Rocky Mountain region belong to a single ecotype. The lack of photoperiodic flowering response would further substantiate this conclusion.

From a practical stand point, our observations seem to suggest that a single variety of each grass species suitable for reclamation could be developed for use in a wide range of mountainous environments. However, to ensure a wide range of adaptability and to avoid the dangers of monoculture, a multiline variety of each species composed of improved genotypes of several locales is desirable.

A brief comment on the method of planting technique in mountain test sites may be in order. Many techniques have been suggested by several workers to get an initial seedling establishment in mountain test sites. Our results show that transplanting container grown grass seedlings (at least 3-4 tillering stage) would be the most effective method of obtaining immediate cover on drastically disturbed sites in extreme climatic areas. Brown (1976) has made similar observations and suggested their use as a reclamation technique.

CONCLUSION

Local populations of grass species collected from different regions of Alberta's Rockies appear to show similar photoperiodic responses for flowering. The results obtained from transplanting in mountain test sites seem to provide no evidence for the existence of any ecological barrier which limits the utilization of native grass species within Alberta's Rocky Mountain region. It seems that populations of each species have enough genetic flexibility so that plants from different locales can be moved successfully within the mountain region of Alberta. Transplanting container grown grass seedlings was found to be very effective in obtaining immediate cover on disturbed areas.

There are many problems prohibiting the large scale agricultural production of native grass seed. Seed shattering, low yields, hairs and awns which must be removed, intermittent flowering, low fertility and uneven ripening are factors which will make native grasses expensive to produce. An economically feasible production level can be acheived through a judicious selection of species and the application of good agricultural research methods.

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TABLE 1: HARVEST DATES IN 1976 AT ELLERSLIE

GENUS AND SPECIES	SOURCE	DATES HARVESTED
Trisetum spicatum	Peyto Lake	June 16, 17, 18
	Whitehorn	June 29
	Mt. Rae	June 29
	Grassy Mtn.	July 12, 20
	Mtn. Park Pass	July 19
	Sunshine	July 19, Aug. 6, 20
	Coal Valley	Aug. 6
Phleum alpinun	Cat Creek	June 30, July 5
	Fortress Mtn.	July 12
	Cat Creek	July 12, Aug. 18
	Barnaby Ridge	July 12, Aug. 18
	Sunshine	July 16, Aug. 20
	Caw Creek	Aug. 20
Festuca saximontana	Grassy Mtn.	July 6
	Sunshine	July 6
	Mt. Rae	July 9, 13, 19
	Barnaby Ridge	July 19
	Pyramid Lake	July 19
	Coal Valley	July 20
Poa alpina	Grassy	July 7, Aug. 19
	Mtn. Park	July 7, Aug. 6, 20
	Coal Valley	July 7, Aug. 6
	Caw Creek	July 8, Aug. 6
	Snow Creek	July 8, Aug. 6
	Sunshine	July 8, 19, Aug. 6, 18
	Pyramid Lake	July 9, 19, Aug. 18
	Ribbon Creek	July 9, 19
	Barnaby Ridge	July 9, 19, Aug. 18
	Forget-Me-Not Mtn.	July 9, 13
	Highwood House	July 9
	Clearwater	July 19
Festuca scabrella	Beauvais	July 9
	Waterton	July 9
	Stavely sub-station	July 9
	Clearwater	July 9
	Ya Ha Tinda	July 9
	Cat Creek	July 9
	Porcupine Hills	July 9
	Whaleback Ridge	July 9
	Snow Creek	July 9
	Caw Creek Ridge	July 9
Poa cusickii	Highwood House	July 12
	Forget-Me-Not Mtn.	July 13

TABLE 1 (cont.)

GENUS AND SPECIES	SOURCE	DATES HARVESTED
Koeleria cristata	Cat Creek	July 12, 19, 27, Aug. 18
	Sheep River	July 12, 27, Aug. 18
	Athabasca Ranch	July 12, 19, 27
	Waterton	July 19
	Ya Ha Tinda	July 19, 27
	Yarrow Creek	July 19
	Beauvais Lake	July 19
	Pincher Ridge	July 19
	Drywood Creek	July 19
	Mt. Stearn	July 19, 27
	Snow Creek	July 19, 27
	Ram Mtn.	July 19
	Devona Lookout	Aug. 20
Agropyron latiglume	Mtn. Park	July 13, 19, 22, Aug. 6, 20
	Caw Creek	July 16, Aug. 6, 19
Festuca idahoensis	Waterton	July 13, 15, 19
	Windsor Ridge	July 14, 15, 19
	Stavely sub-station	July 15, 19
	Porcupine Hills	July 15
Agrostis scabra	Grassy Mtn.	July 15, Aug. 20
Agropyron trachycaulum	Grassy Mtn.	July 15, 20, Aug. 6, 19
	Barnaby Ridge	July 15, 20, 22, Aug. 19
	Mtn. Park	July 16, 20, Aug. 6, 19
	Mt. Stearn	July 20, 28, Aug. 5, 19
	Kootenay Plains	July 28, Aug. 5, 19
	Clearwater	July 28
	Greenock Mtn.	July 28, Aug. 5
	Athabasca Ranch	Aug. 19
	Waterton	Aug. 5, 19
	Porcupine Hills	Aug. 5, 19
Agropyron subsecundum	Kootenay Plains	July 28, Aug. 5, 19
	Clearwater	July 28, Aug. 5, 19
	Rock Lake	July 28, Aug. 5, 19
	Ram River Falls	July 28, Aug. 5, 19
	Greenock Mtdn.	Aug. 5, 19
	Athabasca Ranch	Aug. 5, 19
	Cat Creek	Aug. 5, 19
	Smoky River	Aug. 5, 19
Helictotrichon hookeri	Sheep River	July 15
	Waterton	July 15
	Porcupine Hills	July 15

TABLE 1 (cont.)

GENUS AND SPECIES	SOURCE	DATES HARVESTED
Stipa richardsonii	Pyramid Lake	July 16, Aug. 6
	Cat Creek	July 16, Aug. 5
	Porcupine Hills	July 16
	Grassy Mtn.	July 16, Aug. 6
Stipa comata	Kootenay Plains	July 16, 20, 28, Aug. 5
	Greenock Mtn.	July 20, 28, Aug. 5
Stipa spartea	Greenock Mtn.	July 20, Aug. 5
	Porcupine Hills	July 23
Stipa columbiana	Barnaby Ridge	July 16, 21, 28
	Cat Creek	July 21, 28
	Rock Lake	July 21, 28
	Greenock Mtn.	July 21, 28
Calamagrostis purpurescens	Athabasca Ranch	July 16, Aug. 5
	Plateau Mtn.	July 16
	Clearwater	July 16, Aug. 6
	Kootenay Plains	July 16
	Brule Lake	July 16
	Mtn. Park Pass	July 20, Aug. 20
Danthonia intermedia	Smoky River	July 19
Danthonia parryii	Porcupine Hills	July 19
Oryzopsis hymenoides	Sheep River	July 21
Agropyron albicans	Kootenay Plains	July 21, 23, 27, Aug. 3
	Smoky River	July 26, Aug. 20
	Brule Lake	Aug. 3, 18
	Greenock Mtn.	Aug. 3, 18
Agropyron spicatum	Yarrow Creek	July 21, Aug. 3
	Cat Creek	July 21, 23, Aug. 3, 18
	Windsor Ridge	July 23, Aug. 3
	Waterton	Aug. 3
Agropyron dasystachyum	Ya Ha Tinda	July 23, 26, Aug. 5
	Smoky River	July 26, Aug. 5, 20
	Mt. Stearn	July 26, Aug. 3
	Cat Creek	July 26
	Porcupine Hills	July 27, Aug. 5
	Sheep River	July 27, Aug. 5
	Kootenay Plains	Aug. 3
	Waterton	Aug. 4
	Athabasca Ranch	Aug. 5
	Disaster Point	Aug. 5
	Devona Lookout	Aug. 5

TABLE 1 (cont.)

GENUS AND SPECIES	SOURCE	DATES HARVESTED
Agropyron riparium	Smoky River	Aug. 20
	Kootenay Plains	Aug. 3
	Cat Creek	Aug. 3
Bromus pumpellianus	Disaster Point	July 28
	Athabasca Ranch	July 28
	Rock Lake	July 28
	Kootenay Plains	July 28
	Cat Creek	July 28
	Fortress Mtn.	July 28
Elymus innovatus	Ribbon Creek	Aug. 5
	Ya Ha Tinda	Aug. 5
	Snow Creek	Aug. 5
	Ram Mtn.	Aug. 5
	Coal Valley	Aug. 5
Calamagrostis canadensis	Coal Valley	Aug. 10
Agropyron smithii	Waterton	Aug. 25

TABLE 2: GRASSES USED IN MOUNTAIN TRANSPLANT STUDIES

1975 Establishments

GENUS AND SPECIES	SOURCE	ELEVATION
Agropyron dasystachyum	Exshaw	4500ft.
Deschampsia caespitosa	Whitehorn Mtn.	6000ft.
Stipa columbiana	Pigeon Mtn.	5500ft.
Trisetum spicatum	Mt. Rae	7500ft.
Poa alpina	Mt. Rae	7500ft.
Poa arctica	Whistlers Mtn.	7700ft.

1976 Establishments

GENUS AND SPECIES	SOURCE	
Agropyron dasystachyum	Provincial wide selection	
Agropyron latiglume	Peyto Lake	7200ft.
Agropyron trachycaulum	Banff Flats	4500ft.
Agropyron subsecundum	Kootenay Plains	4500ft.
Bromus pumpellianus	Provincial wide selection	
Festuca saximontana	Caw Creek Ridge	6500ft.
Koeleria cristata	Provincial wide selection	
Phleum alpinum	Peyto Lake	7200ft.
Poa alpina	Whitehorn Mtn.	6000ft.
Poa arctica	Whistlers Mtn.	7700ft.
Stipa columbiana	Pigeon Mtn.	5500ft.
Trisetum spicatum	Mtn. Park Pass	6700ft.

TABLE 3: RESULTS OF MOUNTAIN TRANSPLANTS

1975 Establishments

Site	No. of Plants	% Survivors July, 1977	% Reproducers July, 1977
Bankhead Coalmine 4750ft. near Banff	48	48	12
Bighorn Dam 4400ft. near Nordegg	176	84	48
Caw Creek Ridge 6500ft. near Grande Cache	128	68	58
Highwood Pass 7239ft. near Canmore	96	85	59
Luscar Coalmine 5700ft. near Hinton	96	78	50
Nordegg Coalmine 5500ft. near Nordegg	64	89	50
Racehorse Creek Coalmine 6500ft. near Blairmore	128	68	62
Average of 7 sites	736 Total	74	48

TABLE 3 (cont.)

1976 Establishments

Site	No. of Plants	% Survivors July, 1977	% Reproducers July, 1977
Bighorn Dam 4400ft. near Nordegg	160	94	43
Caw Creek Ridge 6500ft. near Grande Cache	160	99	11
Corral Creek Sheep Range 3700ft. near Grande Cache	160	90	46
Cuthead Creek Roadbed 6080ft. near Banff	160	75	48
Grassy Mtn. Coalmine 6000ft. near Blairmore	160	84	20
Johnston Creek Horse Corral 6460ft. near Banff	160	100	no data
Maligne Canyon Roadbed 4340ft. near Jasper	160	99	32
Mountain Park Coalmine 5900ft. near Hinton	160	96	37
Nordegg Coalmine 5500ft. near Nordegg	160	64	16
Prospect Coalmine 6700ft. near Hinton	160	69	12
Racehorse Creek Coalmine 6500ft. near Blairmore	160	86	52
Snow Creek Pass Roadside 7220ft. near Banff	160	81	22
Tent Mountain Coalmine 7000ft. near Coleman	158	87	30
Average of 13 sites	2078 Total	86	31

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CHALLENGES IN COOPERATIVE RECLAMATION RESEARCH

by

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Thirty to forty years ago the development of efficient earthmoving equipment made it feasible to extract coal and other minerals by surface mining methods. Initially the acreage affected was small. The mine operators who recognized their responsibility to reclaim the disturbed land were the pioneers in mined land reclamation. Reestablishment of vegetation was the immediate objective and reclamation technology was borrowed from agricultural and forest sciences. As the surface mining industry expanded and the acreage disturbed increased, the need for more intensive research became necessary. Applied research focused on vegetation establishment. Initially the interest was in species adaptation and the influence of spoil characteristics and site variables on plant survival and growth.

From this modest beginning the scope of reclamation research has expanded to include such diverse subjects as: factors to consider in planning a mining operation; practical earth movement and placement methods that complement the reclamation plan; restoration programs to meet specific land use objectives. Although applied research still dominates, more sophisticated reclamation technology has stimulated more interest in basic research. Today's research priorities recognize the need to minimize the negative impact of surface mining on our environment without jeopardizing the financial integrity of the mining industry.

Policies relating to the administration of reclamation research programs demonstrate a recognition of the complexity of the problems, and the interaction between many facets of reclamation technology. To meet the challenge, multi-disciplinary research groups were formed to attack in depth, specific problem areas. These units are effective but the scope of their research is limited by financial and physical constraints. A logical alternative appears to be an expansion of cooperative reclamation research. This is not a new concept but we have not developed it to its full potential.

There may be different interpretations of cooperative reclamation research, so it is appropriate to explain how the term will be used in subsequent discussions. The basic concept is to broaden the scope of existing research programs by encouraging the formation of cooperative units that are composed of two or more research groups. Selective development of a cooperative unit will permit the most efficient use of the expertise and facilities available to research a priority problem. Until the concept has proven its value, funding may be a problem because it breaks with tradition. Initially, it may be advisable to fund each research project in the cooperative unit individually. Ultimately it would be advantageous to fund the cooperative unit and delegate the administration of the project to a member that has management capabilities.

The opportunities for cooperative reclamation research exist in every research group. Perhaps the greatest potential occurs in our colleges and universities. This is particularly true for institutions located in localities where surface mining contributes substantially to the regional economy. The challenge to the academic community is to recognize its opportunities and to strive for a leadership role in cooperative reclamation research.

Cooperative projects may involve administrative units within the institution, government research groups, or other colleges and universities. High priority should be placed on cooperative research with outside groups. These contacts can be mutually beneficial by introducing new perspectives and by sharing research capabilities. It will not be an easy task because it will mean dismantling established traditions and revising the missions of established research groups.

The success of expanded cooperative reclamation research in colleges and universities depends upon recognition and support by top administrative officials. Historically, many of the current research projects in our academic institutions resulted from the interest and dedication of one or two scientists. The administration approves projects but staff members often fail to receive adequate tangible administrative support. Without this adminstrative assistance, the scope of these projects is limited and the opportunities for expansion are restricted.

Administrative support of reclamation research should include the establishment of procedures and facilities for administering, coordinating, and financing cooperative projects. Consideration should be given to modification of teaching schedules to accommodate research priorities. Establishment of research review procedures is essential to maintain a high standard of quality and acceptable levels of accomplishment. Administrative support services could relieve the individual scientist of many of the routine duties usually associated with cooperative research.

The challenge to government research organizations is to overcome administrative and political constraints that discourage cooperative projects. These may be real or imagined. Administrative restraints involve problems associated with the development of appropriate cooperative agreements, legal commitments of appropriated funds and personnel management. The existence of complex cooperative agreements indicates these constraints can be overcome with diligence and ingenuity. Politically, the concern may be that cooperative research will dilute the prestige of the government agency thus reducing its political strength when attempting to justify continuing or expanded appropriations. There may be validity to this concern, but documentation of the results of high quality, productive, cooperative research projects can be equally impressive to legislative bodies.

Potential cooperators must also recognize that government agencies have much more to offer than financial assistance. One of the most attractive incentives is a capability to conduct field studies of limited or regional scope. Cooperation with government agencies also provides continuity for long term research projects. Existing facilities and equipment can be made available to cooperators. The acquisition of specialized equipment may be expedited by government purchasing procedures.

Mining companies seldom have the capability or desire to conduct reclamation research, but they can and do serve important functions in the research process. The challenge in this case is to fully utilize the available research support. The mining industry should be invited to participate in research programs. They can cooperate by identifying and defining specific reclamation problems, recommending appropriate variables for measurement and analysis, providing suggestions regarding establishment procedures and assisting in the interpretation of research results. Cooperating companies can be utilized to test the practicality of research results and make suggestions regarding modifications that will improve efficiency or reduce costs. The adoption of reclamation procedures developed through cooperative research programs is an important testimonial to their practicality and value.

Negotiating cooperative programs with industry requires an understanding of corporate philosophies and structure. As corporate entities they are production oriented and cost conscious. Many are suspicious of programs that may increase costs or intensify regulations that govern their operation. Corporate executives and top managment personnel often do not understand or appreciate the research process. However, if they are advised of the plans, progress, and results of cooperative research many companies will provide important support services.

A stigma regarding the credibility of research conducted in cooperation with industry does exist. Maintenance of a high standard of research competence and candid reference to cooperative projects with industry will satisfy many unbiased critics.

While academic institutions, government agencies, and the mining industry offer the greatest potential for cooperative reclamation research, other groups should be encouraged to participate. Regulatory agencies and environmental groups should be involved in cooperative reclamation research. In addition to financial support, the regulatory agencies can assist with problem definition and selection, and interpretation of results. In return they will become more familiar with research procedures and have immediate access to new reclamation technology. The traditional role of environmental groups has been to expose conditions contributing to environmental degradation. They can serve equally well as consultants for research programs that are attempting to understand, alleviate, or correct problems attributable to the surface mining industry.

Private consulting firms have proliferated and prospered in recent years. Many have competent multi-disciplinary staffs that provide the capability for quality research. It is conceivable they could also serve as coordinators of cooperative reclamation research. Their staff and facilities could be used to administer cooperative programs involving any of the groups previously mentioned. It is also possible they could be assigned segments of cooperative projects initiated by other research groups.

This certainly does not identify all opportunities for cooperative reclamation research. The intent was to demonstrate the need for this research and to identify situations where it could function effectively. Challenges presented for consideration are as follows:

1. Expansion of cooperative research within our academic institutions with high priority given to outside cooperators.

2. Governmental research groups need to overcome administrative and political constraints that inhibit participation in cooperative research.

3. Recognition that government agencies have more to offer than financial assistance.

4. Utilization of the support the mining industry can provide.

5. Participation by regulatory agencies and environmental groups.

6. Utilization of private consulting firms as administrators of cooperative reclamation research projects.