CLRA

NINTH ANNUAL MEETING
CANADIAN LAND
RECLAMATION ASSOCIATION

RECLAMATION IN MOUNTAINS, FOOTHILLS AND PLAINS: **DOING IT RIGHT!**

AUGUST 21-24, 1984
Calgary, Alberta, Canada

CANADIAN LAND RECLAMATION ASSOCIATION

NINTH ANNUAL MEETING

RECLAMATION IN MOUNTAINS, FOOTHILLS AND PLAINS

DOING IT RIGHT!

AUGUST 21 - 24, 1984

CONVENTION CENTRE

CALGARY, ALBERTA

ACKNOWLEDGEMENTS

These proceedings are the result of dedication and commitment of many people including members of the Canadian Land Reclamation Association, technical contributors within and outside Canada, industrial organizations and government bodies. The contribution of all these groups to the Ninth Annual Meeting is gratefully acknowledged.

In particular, we would like to recognize the financial assistance provided by:

Alberta Environment
Alberta Oil Sands Industry Environmental Association
Alberta Public Affairs Bureau
R. Angus Alberta Limited
BP Canada Inc.
Burnco Rock Products Ltd.
Canadian Land Reclamation Association, Alberta Chapter
Prairie Seeds Ltd.
Westmin Resources Limited

and the support of the meeting by Management and Staff of the following groups:

Alberta Energy Resources Conservation Board
Alberta Sand & Gravel Producers Association
Coal Association of Canada
Canadian Petroleum Association
XV Winter Olympic Organizing Committee
Gregg River Resources Limited
Gulf Canada Limited
Parks Canada
Reid, Crowther and Partners Limited
Bank of Montreal

The Organizing Committee for the Ninth Annual Meeting was:

Chairman	Jennifer Hansen, J. Hansen Consulting
Functions	Lynda Watson, Techman International Limited
Technical Sessions	P.D. Lulman, TransAlta Utilities Corporation
Registration	A.J. Kennedy, Esso Resources Canada Limited
Public Relations	M.K. Ross, Crows Nest Resources Limited
Field Tours	Karen Natsukoshi, Manalta Coal Limited
	Julia Fulford, Fording Coal Limited
Commercial Displays	L.A. Panek, Montreal Engineering Company Ltd.
Audio Visual	A. Schori, Monenco Consultants
Alternate Programs	Holly Quan, TransAlta Utilities Corporation

Citation

The citation of this document in all references is:

1984 Canadian Land Reclamation Association
Ninth Annual Meeting, Calgary, Alberta, August 21st - 24th

CANADIAN LAND RECLAMATION ASSOCIATION
PROCEEDINGS OF THE NINTH ANNUAL MEETING

TABLE OF CONTENTS

Wednesday, August 22

Thursday, August 23

13. Managing Minesoil Development for Productive Reclaimed Lands
(W. SCHAFER)

14. Reclamation Monitoring: The Critical Elements of a Reclamation Monitorin Program
(R.L. JOHNSON, P.J. BURTON, V. KLASSEN, P.D. LULMAN, D.R. DORAM)

15. Plains Hydrology and Reclamation Project: Results of Five Years Study
(S.R. MORAN, M.R. TRUDELL, A. MASLOWSKI-SCHUTZE, A.E. HOWARD, T.M. MACYK, E.I. WALLICK)

16. Highvale Soil Reconstruction Reclamation Research Program
(M.M. BOEHM, V.E. KLASSEN, L.A. PANEK)

17. Battle River Soil Reconstruction Project: Results Three Years Afte Construction
(L.A. LESKIW)

18. Gas Research Institute Pipeline Right of Way Research Activities
(C.A. CAHILL, R.P. CARTER)

19. Subsoiling to Mitigate Compaction on the North Bay Shortcut Project
(W.H. WATT)

20. Effects of Time and Grazing Regime on Revegetation of Native Range Afte Pipeline Installation
(M.A. NAETH, A.W. BAILEY)

21. Revegetation Monitoring of the Alaska Highway Gas Pipeline Prebuild
(R. HERMESH)

22. Post-Mining Groundwater Chemistry and the Effects of In-Pit Coal Ash Disposal
(M.R. TRUDELL, D. CHEEL, S.R. MORAN)

23. Assessment of Horizontal and Vertical Permeability and Vertical Flow Rates fo the Rosebud - McKay Interburden, Colstrip, Montana
(P. NORBECK)

24. Accumulation of Metals and Radium - 226 by Water Sedge Growing on Uranium Mil Tailings in Northern Saskatchewan
(F.T. FRANKLING, R.E. REDMANN)

25. How Successful is the Sudbury (Ontario) Land Reclamation Program?
(P. BECKETT, K. WINTERHALDER, B. McILVEEN)

26. Methodology for Assessing Pre-Mine Agricultural Productivity
(T.A. ODDIE, D.R. DORAM, H.J. QUAN)

27. An Agricultural Capability Rating System for Reconstructed Soils
(T.M. MACYK)

CANADIAN LAND RECLAMATION ASSOCIATION NINTH ANNUAL MEETING

OPENING REMARKS

J.M. KING

CHAIRMAN, ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL

Ladies and Gentlemen, it is my pleasure and privilege to welcome you to this, the Ninth Annual Meeting of the Canadian Land Reclamation Association and to those of you from outside our province, a warm welcome to Alberta. This is the second Annual Meeting of your association to be held in Alberta. We consider this a recognition of the numerous people involved in reclamation within the province and are honored to be your host for the next few days. As a means of setting the stage for the technical presentations I would like to introduce you to the province, our approach to reclamation, and some of our activities.

The Alberta landscape is extremely varied from plains, to foothills, to mountains and all the transitional zones in between resulting in a land base that supports agriculture, forestry and wildlife as well as specific developments built by man. Additionally, we have been blessed with numerous petroleum, mineral and aggregate resources beneath the land surface which provide the base for extensive industrial activity. This multi-varied demand placed on the land base has resulted in Alberta recognizing the need to reclaim disturbed lands so that the long-term potential for varied land utilization is maintained.

At present we have: 11 operating major coal mines with over 19,000 acres disturbed, two oil sands mining operations with over 21,000 acres disturbed, one commercial in-situ oil sands operation under construction, over 65,000 acres affected by sand and gravel operations, an operating total of over 17,000 oil and gas wells with another 5,000 being drilled annually over 200,000 miles of pipelines of one size or another.

There is, therefore, a need for interaction between the developer, government, present and future land users and the general public to ensure that the views of each are considered. Within the province this has been accomplished through the public hearings process, the establishment of community based steering committees for major plains coal developments, constant dialogue with resource industry committees and ongoing discussion with specific companies.

An organization such as the Canadian Land Reclamation Association is valuable because if fosters better communications and understandings between the concerned individuals, and provides a window through which information can be exchanged. This communication exchange crosses provincial boundaries as well as those of different industries, all happening in an informal setting. I believe this goes a long way towards keeping people abreast of the concerns of others, and the latest technology and helps to establish a sense of commonality regarding the objectives of reclamation.

The approach to reclamation in Alberta has tended to follow ten year cycles with respect to requirements and procedures.

Before 1963, there was no requirement for the reclamation of disturbed lands in Alberta. The only consideration was in the Mines and Minerals Act which required that mined areas be left in a non-hazardous condition based on safety.

In June of 1963, the Surface Reclamation Act was enacted to cover specified activities occurring on what are classified as surveyed lands. This Act created the Surface Reclamation Council and the reclamation certification process. The standards of the day could be called "Remedial" in that reclamation was a post-development activity with the return of the topographic land surface being the requirement. Soil conservation was not required.

In 1973, the Land Surface Conservation and Reclamation Act was passed. The concept of the Council was continued. The changes in reclamation requirements included the need for soil conservation, the need for revegetation and a requirement that industry plan reclamation as part of the development planning. Not only was integrated planning required but the government responded with the integrated committee review system. Research support and cooperation was initiated as was a flexible approach with respect to procedural system.

From 1983 and on in to the future, the approach has been and will continue to be to review and evaluate existing procedures and legislation in light of new found knowledge, and technical and economic change. This effort includes the ongoing review of the Land Surface Conservation and Reclamation Act, the evaluation of different approval procedures and their overlap and the development of updated information packages for industry. The intention is to simplify the systems and reduce the duplication while still maintaining a level of flexibility that permits a response to changed conditions and maintains a balance between environmental protection and the development of our resources.

The reclamation activities of the Land Conservation and Reclamation Council occur on three fronts: Administration of the Act and regulations; reclamation operations; and research.

- The administration of the Act and the regulations for designated surface operations is the major activity and involves the review of applications, issuing of approvals, enforcement, and certification.

- Since 1976, the Council has been conducting the actual reclamation of areas mined prior to 1963 on lands owned by the province. This program has included reclamation of such sites as municipally owned landfill sites and sewage lagoons. In all, more than 800 projects have been completed resulting in more than 8,000 acres of reclaimed land being made available for other useful activities.

- Finally, the Council is the funding authority for reclamation research in Alberta. The Reclamation Research Technical Advisory Committee recommends and monitors studies which must meet a specific need identified by either industry or the review agencies. Most of the projects result from industry initiation with some being jointly funded. Industry is involved in the review process.

The results of this cooperation are such projects as the Battle River Research Project, and Plains Hydrology Research Project and a major effort with the Oil Sands Environmental Study Group. You will be hearing about these efforts in the presentations tomorrow morning.

Also, a major planning venture related to the development of the Villeneuve gravel deposits near Edmonton has been initiated where the local municipality, the Department of the Environment and the aggregate industry are cooperating in the development of plans for the long-term reclamation of the area.

These practices, we are aware are similarly happening between government, industry and the public in other provinces, and in the United States as evidenced by the number and variety of presentations to be made at this conference.

This effort must be continued so that industry is able to develop the resources while still ensuring the return of the land base for future users. Flexibility must also be integral to any system:

1. to permit adjustments by industry to economic changes;

2. to permit the introduction of new development technology into operations; and

3. to encourage the development and use of updated reclamation information.

With so much happening in so many industries and at so many levels, there is an overriding need to maintain support for active interaction. This includes groups such as the Canadian Land Reclamation Association. These groups have an important role to play in the dissemination of information to all sectors as well as providing a forum for the personal exchange of views and ideas. With continued and improved dialogue as provided by conferences such as this one we will all improve our level of knowledge and recognition of the other persons' concerns. The benefits will accrue for our mutual betterment now and into the future.

I am sure the many technical presentations will be enlightening and thought-provoking. I encourage all of you to get to know your counterparts, exchange some ideas, and gain a better understanding of each others' concerns.

Once again, welcome to Alberta and enjoy your stay.

WILDLAND RECLAMATION AND REFORESTATION OF TWO COAL STRIP MINES IN CENTRAL ALBERTA

J.C. BATEMAN AND H.J. QUAN

MONENCO CONSULTANTS LIMITED, TRANSALTA UTILITIES CORPORATION

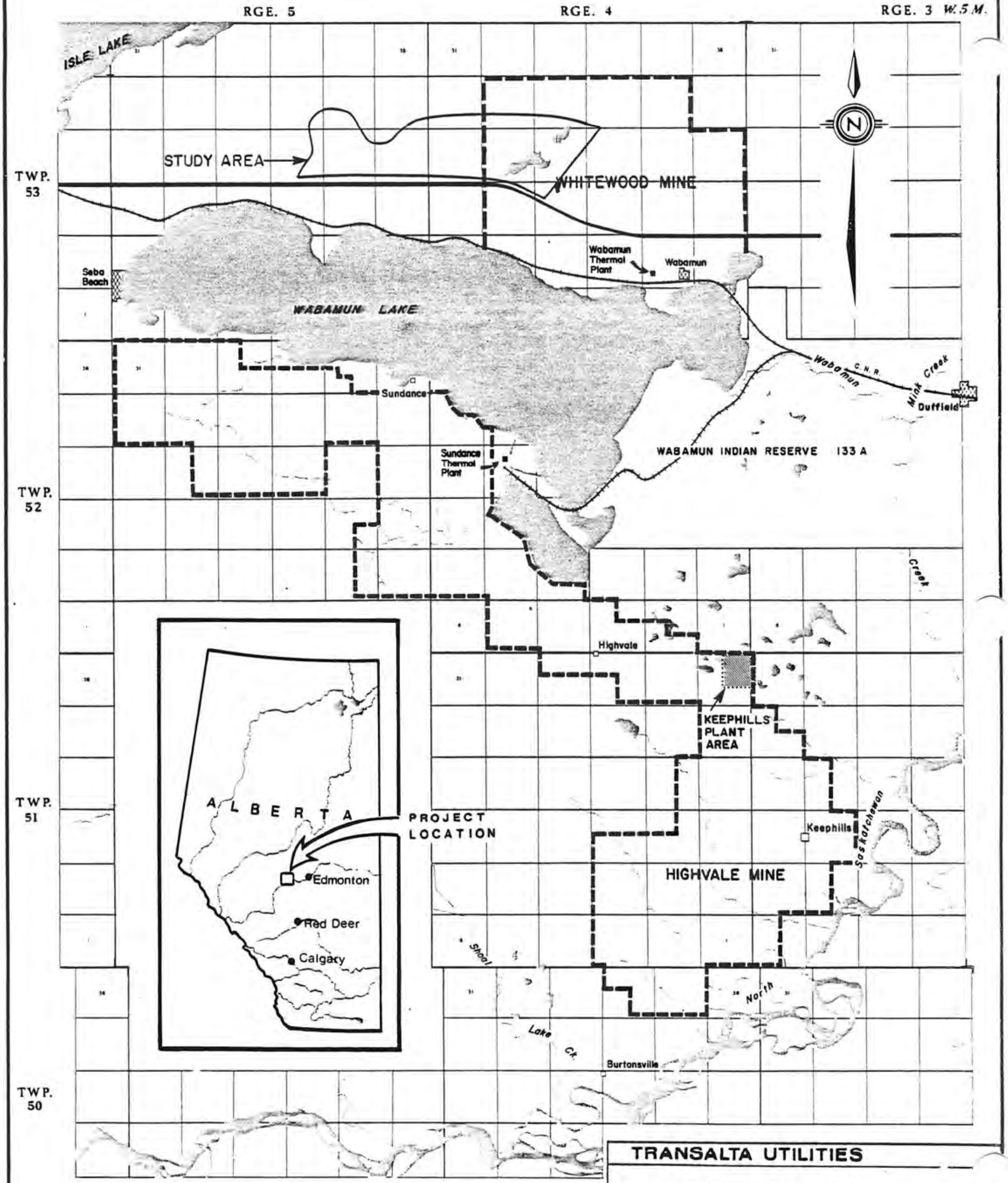
ABSTRACT

The productivity and capability of forested areas at TransAlta Utilities Corporation's Whitewood and Highvale mines have been quantified. This information has been used to evaluate the success with which mined areas supporting forest stands have been restored to their original capability. Spruce stands planted on mined land at Whitewood in 1959 have yields and densities far below that of undisturbed sites. The capability of these areas to support spruce forests is, however, comparable to undisturbed sites. The yield of naturally established deciduous stands on mined lands is similar to undisturbed sites, however the densities are far greater. This is a function of stand age and has little to do with the productive potential of the area. The capability of mined land to support deciduous stands at the Whitewood mine is equal to and even slightly greater than undisturbed areas.

INTRODUCTION

TransAlta Utilities Corporation operates two coal strip mines in Central Alberta (Figure 1). The production of the two mines totals roughly 10,500,000 tonnes of thermal grade coal. The combined mine permit areas encompass 16,962 hectares (ha) of which approximately 150 ha are mined annually. By the end of 1982, 1307 ha had been mined and 646 ha had been reclaimed. The objective of reclamation is to return mined land to capabilities equal to or better than those that existed before mining (TransAlta Utilities Corporation 1983).

Before mining proceeds, surveys and inventories of existing resources are undertaken to provide information on the land use capabilities of undisturbed land. This information is then used for the development of long-term reclamation goals and land use objectives for areas affected by mining. Present land use in the area of the Whitewood Mine north of Wabamun Lake is split roughly in half between agricultural areas and wildland areas which include peatlands, upland forest and water bodies (Monenco Limited 1983a). At the Highvale Mine south of Wabamun Lake, agricultural land uses account for two-thirds of the mine permit area and wildland land uses account for approximately one-third of the mine permit area (Monenco Limited 1983b). Land use plans for the two mines propose a variety of end land uses including agricultural, industrial and recreational land with the development of



TRANSALTA UTILITIES

LOCATION PLAN

MONENCO LIMITED

1983-11-30 DATE	CPL	8218-8 WORKORDER	SUBCODE	017 SYSTEM	FIGURE 1

wildland habitat as a specific goal (EPEC Consulting Western Ltd. and Earthscape Consultants 1983, Montreal Engineering Limited 1980).

This paper is a summary of the techniques used to quantify the capability of wildland and forested areas to support productive forest growth within the Highvale and Whitewood mine permit areas and the means of comparing this to areas affected by mining.

METHODS

Background

The growth of forests is the result of many complex and interacting factors which collectively control the growth of individual trees (Kozlowski 1971). The major components are soil depth, soil texture, profile characteristics, mineral composition, steepness of slope, aspect, microclimate and species. To compare the productivity of different forest sites, an index that best represents the sum total or combined effect of all these factors on individual tree growth is required. The most direct approach would be to measure the volume of wood or biomass produced per unit of time, just as agronomists measure crop yield per hectare per year. The actual yield of forests, however, is not only influenced by site factors, but also by stand age and density, genetic factors and the biotic history of the stand. The actual volume increment measured in any one year, therefore, may not necessarily reflect the true capability of a given forest site. The traditional approach to predicting the productivity or capability of a given site would be to use a regression equation or model that combines all the measurable parameters that affect tree growth into an estimate of productivity based on thousands of sample sites in and around the area of study. However, since the number of growth patterns resulting from such a complex matrix are virtually infinite (Bickerstaff et al. 1981) and because reclaimed environments rarely resemble the original environment, the estimation of whole forest productivity on reclaimed areas could not be determined accurately or economically without a model that would combine hundreds of measurable and non measurable environmental parameters.

To overcome the problems of the effect of stand condition on productivity and the complexity of predicting site capability using countless environmental parameters, the height of free-grown trees of a given species at a particular reference age (generally 50 years) is commonly used as an index of site quality (Baker 1950, Curtis et al. 1973, Spurr and Barnes 1980, Stage 1963). The height growth of a dominant tree is less affected by stand density than other measures of tree dimensions (i.e., diameter); it is also a sensitive measure of differences in site and is easily determined in relation to age (Baker 1950, Carmean 1968). By using a free-grown or dominant tree, the effects of stand density and competition on tree growth are removed. Height may thus be used as an index of site quality in stands of varying density, age and silvicultural history (Spurr and Barnes 1980).

For the Whitewood and Highvale mine permit areas, both forest stand productivity (in terms of wood volume and biomass) and the height of dominant free grown trees at a particular reference age (site index) have been used to evaluate the site capability of natural undisturbed forest stands. These have been compared to reforested areas on mined land. The sampling methodology for each method is detailed below.

Forest Productivity Assessment

Native, undisturbed forest stands in the Whitewood and Highvale mine permit areas were sampled using a traditional timber cruise approach. Vegetation types were first grouped together on the basis of species composition. A total of 176 sample sites were then distributed among five forest cover types on a random grid. Point sampling or variable plot radius techniques using wedge prisms were used to define the sample size at each site. All trees regardless of species were tallied if stem overlap was evident when the tree was viewed through the prism from a temporary sampling point that served as a plot centre. For each tree within the plot, the species, total height, age and diameter at breast height (dbh) were recorded. Heights were determined using a clinometer, dbh by a diameter tape and ages using an increment borer. Total timber yield in cubic meters per hectare for each stratum by diameter class and species were determined using volume equations developed by the Alberta Forest Service (Alberta Forest Service 1979). The biomass of each plot was calculated with biomass equations published by the Northern Forest Research Centre (Singh 1982) using total height and dbh. Stand density was calculated using the stem frequency constant for each prism used (Husch et al. 1982). The mean annual increment of each sample site was determined by dividing the total yield by the age of the stand.

Site Capability Assessment

Single dominant trees of white spruce, balsam poplar, aspen, black spruce and jack pine were felled at 61 locations throughout the Highvale and Whitewood mine permit areas. Sample sites were selected to provide a complete range from best to poorest growing conditions as evidenced by height in relation to age, soil, slope and exposure factors. The tallest dominant tree was felled and sectioned at one metre intervals at each plot location. Discs were then labelled and taken to the Wood Technology Laboratory at the University of Alberta for analysis using a Swedish tree ring measuring instrument (Addo-X).

The age associated with a given section at a known height was then determined by subtracting the number of annual rings in that section from the total age of the tree. The pattern of height growth for each tree over its entire course of development was then plotted. The results for each species at each mine were then combined to give an average growth curve. Growth curves from spruce stands planted on mined areas in 1959, and from naturally established aspen stands on abandoned mine areas were then compared to their native counterparts on undisturbed sites at the exact same stage of development.

RESULTS AND DISCUSSION

Forest Productivity

The volume and density of the forest stands sampled are summarized in Table 1. The yield data has been presented graphically with standard deviations in Figure 2. The native white spruce stands are the most productive of those sampled yielding 361 and 281 cubic metres per hectare at Highvale and Whitewood, respectively. These two stands also exhibit the lowest densities of the natural stands. The volume is therefore distributed over a fewer number of stems than in the other native stands. Spruce trees up to 23 m in height and 38 cm in diameter are not uncommon while balsam poplars as large as 46 cm dbh and 22 m in height were also found in isolated areas in these stands. Stand ages vary from 46 to 87 years with an average of 70 years. These stands typically occupy gleyed profiles where they have been protected from ground fires and have been allowed to develop to the climax stage.

The yields of the three deciduous stands on undisturbed areas (aspen and mixed deciduous stands at Highvale and mixed deciduous stands at Whitewood) are all similar producing approximately 200 m^3/ha. The naturally established deciduous stands on reclaimed areas have yields similar but slightly less than their native counterparts at 158 m^3/ha. The stocking densities, however, are much higher in the deciduous stands on reclaimed land than most stands on undisturbed sites. These

Table 1

Summary of Yields and Densities of Native and Reclaimed Forest Stands at Whitewood and Highvale

Stand Type	Average Yield* (m^3/ha ± SD)	Average Density Stems/ha
Highvale (native)		
Aspen	185 ± 125	1784 ± 1084
Mixed Deciduous	208 ± 108	1684 ± 1486
White Spruce	361 ± 42	1131 ± 213
Jack Pine	106 ± 17	2354 ± 1540
Black Spruce	204 ± 75	2802 ± 2069
Whitewood (native)		
Mixed Deciduous	171 ± 114	2135 ± 2514
White Spruce/Poplar	281 ± 281	1447 ± 725
Black Spruce	158 ± 109	2418 ± 1023
Whitewood (reclaimed)		
White Spruce (planted)	25 ± 7	1087 ± 323
Deciduous (naturally invaded)	158 ± 97	7233 ± 5736

* 0.0 cm stump height to 0.0 cm top diameter

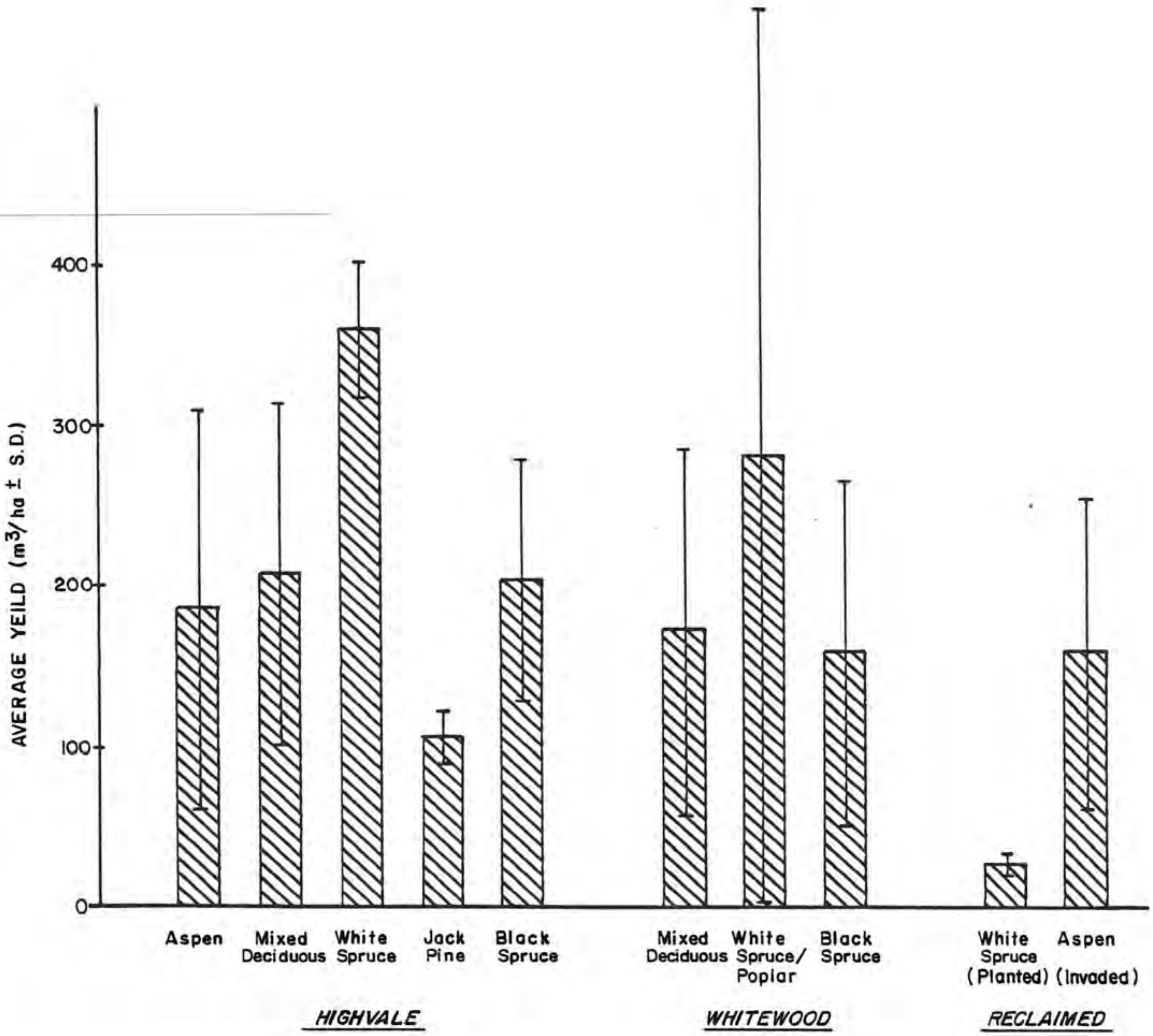


FIGURE 2
TOTAL YIELD OF NATIVE AND
RECLAIMED STANDS

higher densities on disturbed sites are not unexpected and are typical of young deciduous stands in the Whitewood area and elsewhere. The older deciduous stands on undisturbed areas have lower densities due to the high sapling mortality rates that typically occur at canopy closure. High mortality rates are also expected to occur in the young deciduous stands on mined areas as they mature. Although the present yield of the deciduous stands on mined areas are comparable to the yields on undisturbed areas at a much younger age, they are not expected to increase much beyond their present yield due to the associated increase in tree mortality. Instead, the same yield is likely to be distributed over a fewer number of stems as competition increases.

The yield of the white spruce plantation on the reclaimed area is much lower than spruce stands on undisturbed sites. The average stocking density is 1087 stems/ha which is the lowest density of the stands sampled. Tree heights average 5 m and range from 2.7 m to 6.5 m and the average dbh is 7 cm with a range from 3.4 cm to 12.3 cm. The stand is properly spaced and is typical of a fully stocked stand without any competition. Mortality rates in this stand will be minimal and the total yield will continue to increase without competition until the stand matures.

Site Capability

Growth curves for all major tree species have been prepared as a baseline to compare the growth achieved on mined areas. For the purposes of this paper, however, growth curves are only presented for species of which there is data from trees growing on mined land. At present, there exists no data for the height growth of trees growing on reclaimed portions of the Highvale mine. However, as this information becomes available from planting trials, it will be compared to the baseline information.

Growth curves for aspen on undisturbed sites in the Whitewood Mine permit area and on mined lands in the same area are presented in Figure 3. These curves represent the "best fit" lines for all the data collected and are therefore an average of all the trees sampled. The curve for mined areas is only accurate to 30 years. The dotted portion of this curve over 30 years is predicted based on the regression equation. The growth rate beyond this point is, however, expected to decrease and follow the same shape as the curve for undisturbed areas.

From the curves, it is evident that the growth of aspen on mined land is equal to and even slightly greater than the growth achieved on undisturbed soils. At 25 years, undisturbed soils in the Whitewood area produce free-grown aspen 11 m in height whereas free-grown aspen on mined areas are 12 m high. It should be noted that the curve for

MONENCO LIMITED

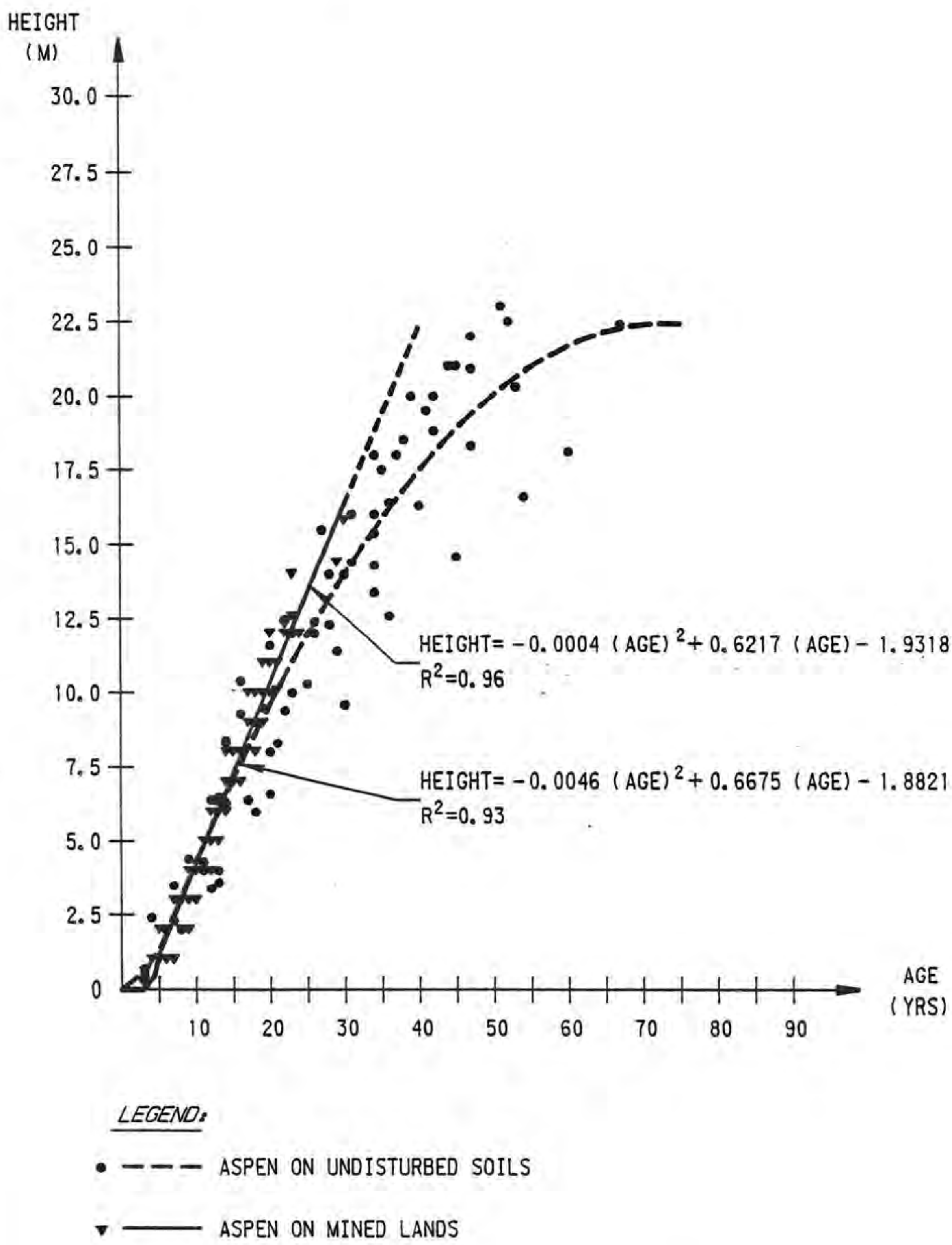


FIGURE 3
TRANSALTA UTILITIES
WHITEWOOD WILDLAND RECLAMATION
HEIGHT GROWTH OF ASPEN POPLAR

N00565.CHT REV. CADD

undisturbed areas is influenced strongly by five points, all coming from one tree on the underside portion of the curve. It is possible that this tree was not a dominant and suffered some degree of competition through its life. If this is true, it should not be included in the sample. The curve would then follow more closely to that of mined areas. Since there is no data to suggest that this tree is not a dominant, it was kept in the sample.

Growth curves for white spruce growing on undisturbed soils and on mined lands in the Whitewood area are presented in Figure 4. The white spruce on the mined areas were planted in raw minespoil in 1959. The growth rates of these trees was initially slower than those on undisturbed sites but once successfully established, they have released and now more closely resemble the rates of native stands. This is most likely a result of optimal spacing. The individual trees in this stand are growing at the maximum possible rate due to the lack of competition from understory species and adjacent trees. This stand will continue to produce at higher growth rates until some growth factor becomes limiting.

MONENCO LIMITED

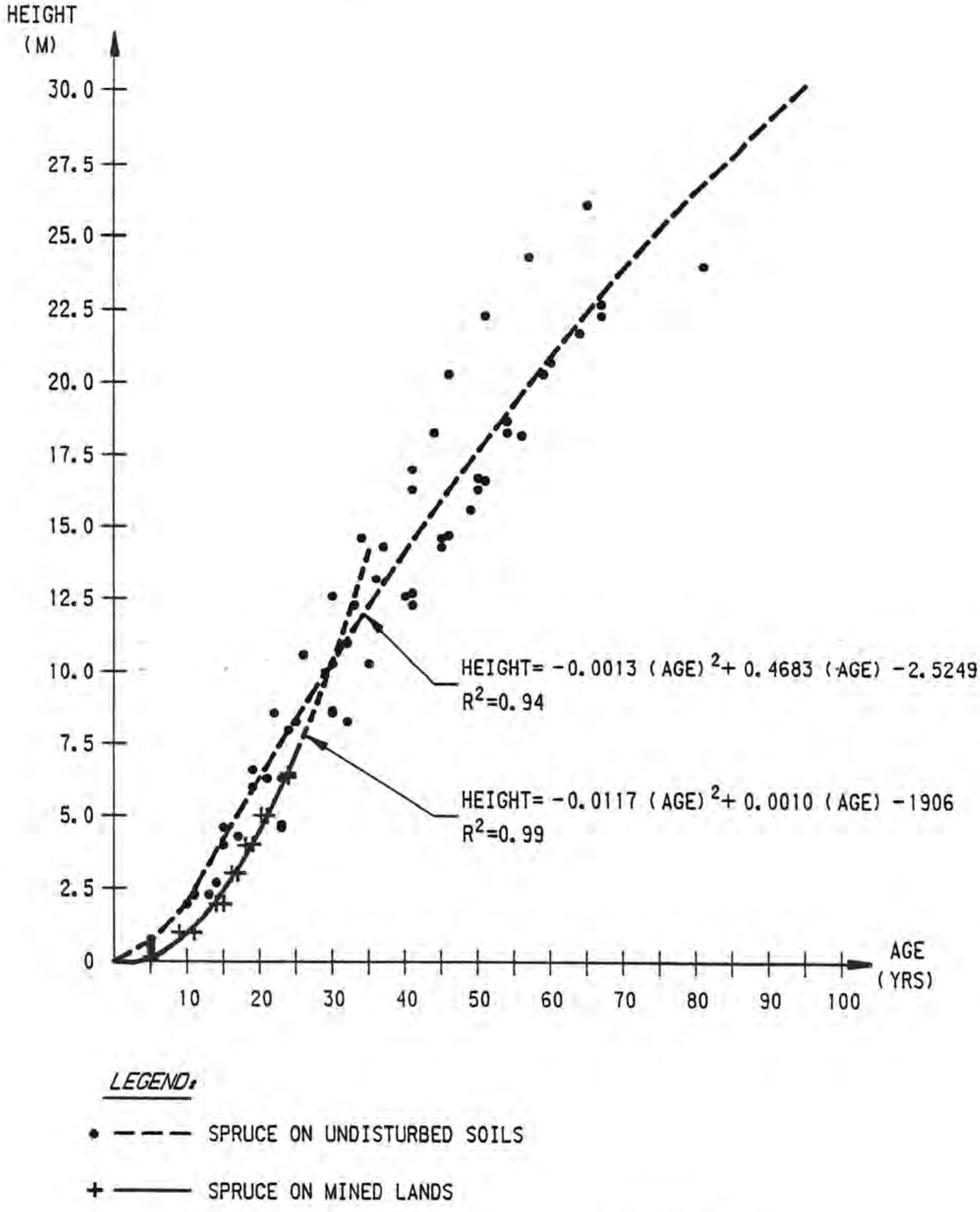


FIGURE 4
TRANSALTA UTILITIES
WHITEWOOD WILDLAND RECLAMATION
HEIGHT GROWTH OF WHITE SPRUCE

CONCLUSION

From the previous analysis, it is evident that mined lands at Whitewood have at least the same and even slightly greater capability to support deciduous and coniferous forests.

Deciduous stands that have invaded naturally on mined areas at Whitewood have the same yields as their off-mine counterpart at a much younger age. As a result, they have a mean annual increment that is approximately three times that of native deciduous stands. This is solely a function of stocking density which is also roughly three times greater in the young stands on mined land than in the older native stands and has little to do with site capability. When site index or height growth is used as a measure of site quality, it is found that growth rates achieved on mined areas are at least equal to and even slightly greater than those on undisturbed soils.

The yield and mean annual increment of spruce stands planted in minespoil are far below that of spruce stands on undisturbed soils due to much lower stocking densities. The growth rates of spruce on minespoil are, however, similar to those on undisturbed soils.

The minespoil supporting these stands has received a minimum of management input. No selective materials handling or topsoil salvage was practised at the time and little effort was spent on re-contouring.

The fact that the capability of this area to support productive forest growth is equal to or better than that of undisturbed areas suggests that mined areas can be reclaimed to meet present regulatory requirements at minimum cost by adopting forests or wildland land uses.

Acknowledgements

Preparation of this review was supported by TransAlta Utilities Corporation. The original projects and reports that were synthesized in this review were also funded by TransAlta Utilities Corporation. Field work, data analysis and report preparation were undertaken by several members of Monenco Consultants Limited environmental staff including Chris Wenzel (Technologist) Marie Boehm (Intermediate Soil Scientist) Peter Guy (Senior Plant Ecologist) and Cam Bateman (Forester). Project managers were Leslie Panek (Senior Supervisory Reclamation Specialist - Monenco) and Holly J. Quan (Environmental Planner - TransAlta).

We wish to record our thanks to Dr. M. Micko, Department of Agricultural Engineering, University of Alberta for technical advise and use of stem analysis equipment at the Wood Science Laboratory, and to Dr. John Railton and Leslie Panek for continued support, guidance and enthusiasm.

References

Alberta Forest Service 1979. Volume Tables. Circular No. TM24. Energy and Natural Resources. June 1979.

Baker, F.S. 1950. Principles of Silviculture. McGraw-Hill, New York.

Bickerstaff, A., W.L. Wallace and F. Evert. 1981. Growth of Forests in Canada - Part 2. A Quantitative Description of the Land Base and the Mean Annual Increment. Environment Canada, Canadian Forestry Service. Information Report PI-X-1.

Carmean, W.H. 1968. Tree height-growth patterns in relation to soil and site. In: Tree Growth and Forest Soils. Oregon State University Press, Corvallis.

Curtis, R.O., D.J. DeMars and F.R. Herman. 1973. Which dependent variable in site index-height-age regressions? Forest Science 20:74-87.

EPEC Consulting Western Ltd. and Earthscope Consultants 1983. The Whitewood Future Land Use Study. Vols. I and II. Prepared for TransAlta Utilities Corporation, Calgary and the County of Parkland. July 1983.

Husch B., C.I. Miller and T.W. Beers 1982. Forest Mensuration 3rd ed. John Wiley and Sons, New York.

Kozlowski, T.T. 1971. Growth and Development of Trees. I. Seed Germination, Ontogeny, and Shoot Growth, 443 pp. II. Cambial Growth, Root Growth, and Reproductive Growth. Academic Press, Inc., New York. 520 pp.

Monenco Limited 1983a. Whitewood West Extension Baseline Data 1983. Prepared for TransAlta Utilities Corporation, Calgary, Alberta

Monenco Limited 1983b. Highvale Wildland Reclamation 1982. Prepared for TransAlta Utilities Corporation.

Montreal Engineering Company, Limited. 1980. Highvale Mine 38 Year Development and Reclamation Plan. Prepared for Calgary Power Ltd.

Singh, T. 1982. Weight Tables for Important Tree Species in the Prairie Provinces. Environment Canada, Canadian Forest Service, Northern Forest Research Centre, Edmonton, Alberta. Forest Management Note No. 14, 4 pp.

Spurr, S.H. and B.V. Barnes. 1980. Forest Ecology. John Wiley and Sons, New York.

Stage, A.R. 1963. A mathematical approach to polymorphic site index curves for grand fir. Forest Science 9(2):167-180.

TransAlta Utilities Corporation. 1983. Annual Report Whitewood Mine March 1983.

SUCCESSFUL INTRODUCTION OF VEGETATION ON DREDGE SPOIL

by

K.W. DANCE, SENIOR BIOLOGIST
GARTNER LEE ASSOCIATES LIMITED

and

A.P. SANDILANDS, BIOLOGIST
ECOLOGISTICS LIMITED

Presented at: Ninth Annual Meeting of the
Canadian Land Reclamation Association,
Calgary, Alberta,
August 22, 1984.

SUCCESSFUL INTRODUCTION OF VEGETATION ON DREDGE SPOIL

K.W. DANCE, GARTNER LEE ASSOCIATES LIMITED

MARKHAM, ONTARIO

and

A.P. SANDILANDS, ECOLOGISTICS LIMITED

WATERLOO, ONTARIO

ABSTRACT

A programme designed to enhance plant colonization of pond dredge spoil is described. Objectives were: to document results of direct introduction of selected plant species on dredge spoil and a newly created pond margin, to document species succession over a five-year period, and to document factors which influenced succession. Wetland and aquatic plants were introduced from local, wild stock sources. Introduction methods included: transplanting, planting wands, broadcasting seed and planting seed. Taxa which flourished include: Giant Burreed, Common Cattail, Broad-leaved Arrowhead, Purple Loosestrife, *Bidens cernua*, Cocklebur and Willow species. Factors affecting success of marshland plant introductions are discussed.

INTRODUCTION:

Basic principles of wild marshland vegetation introduction have been known for several decades (Lamoureux 1957, Kadlec and Wentz 1974). Some use has been made of this knowledge by waterfowl marsh managers and in efforts to reclaim dredge material (Newling 1981) and slurry impoundments (S. Yaich pers. comm. 1984). Much of the dredge spoil work has been in estuarine and marine situations.

Kadlec and Wentz (1974) indicated that well documented case studies of both experimental and operational marsh planting efforts were required to develop guidelines which would improve future planting success.

Natural invasion of a full variety of wild species on disturbed lands may be slow (Bradshaw and Chadwick 1980), although exceptions have been reported in certain freshwater marshes e.g. Smith (1978). Also, since natural succession may not result in vegetation patterns and species most desirable from fish and wildlife habitat, aesthetic and recreation points of view, human intervention is recommended in some instances (Eleuterius and McClellan, 1976).

This paper describes results of freshwater marsh plant introduction in an urban park setting. The programme was designed to reclaim lands which were visible from yards of several dozen expensive homes. Thus, there was a need to hasten and direct vegetation succession.

STUDY OBJECTIVES:

The three objectives were:

- to document results of direct introduction of selected plant species on dredge spoil and a newly created pond margin,
- to document species succession over a five-year period, and

- to document factors which influenced succession.

SETTING:

This study was conducted in West Heights Park, located on the western margin of Kitchener, which is situated in Southwestern Ontario. The mean annual growing season here is 200 days (Brown et al. 1980).

Figure 1 shows the park, pond and adjacent houses in 1983. The 0.70 ha pond is somewhat pear-shaped, with the stem end pointing north. A small temporary pond is located 30 m to the south of the main pond.

HISTORY OF MANAGEMENT:

The study area was developed as a residential subdivision during the last ten years.

The pond and lands immediately adjacent were an open space dedication but underwent little development as they constitute a passive recreation area. The park is administered by the Department of Parks and Recreation, City of Kitchener.

Environmental investigations of the pond begun in 1978, were designed to determine the magnitude of water quality problems in the large pond and to recommend remedial measures (Dance 1979, Dance 1981). Dredging of the pond, rehabilitation of the newly created basin, and reclamation of dredge spoil were three major components of the plan to improve the pond environment.

The pond was dredged using a drag line and spoil was placed on the banks behind straw bale dikes, see Figure 2. Dredging occurred in September 1979 and revegetation of the pond margin began in late October of that year.

FIGURE 1: THE STUDY AREA, SEPTEMBER 1983.

FIGURE 2: THE DRAG LINE AND SPOIL PILES, 1979

REVEGETATION PLANNING:

A plan was developed to ensure rapid, directed revegetation of areas disturbed by dredging. The plan was designed to attain the following objectives at this site:

- to hasten revegetation of pond basin and margin;
- to influence species present:
  - (a) to achieve a mix of aesthetic appeal in terms of form and colour;
  - (b) to provide fish and wildlife food and cover;
- to introduce "desirable" species so that weeds would not become dominant;
- to introduce aquatic species which would compete with algae;
- to stabilize pond margin soils.

Elements of the revegetation plan included attention to:

- concerns and opinions of local residents;
- involvement of a landscape architect to integrate the pond revegetation efforts with that of upland portions of the park;
- use of local wild plant stock;
- planting in locations where environmental requirements of the species would be met;
- timing of revegetation -- late autumn when soils were moist, temperatures cool, propagules were available and certain plant structures were dormant;
- placing straw mulch on dredge spoil once it had dried and was shaped;
- testing soil conditions prior to seeding upland areas.

VEGETATION INTRODUCTIONS:

Most of the plant introductions were made in October 1979, shortly after dredging had been completed. A few additional introductions were made during the growing season of 1980.

Table 1 summarizes the methods used to encourage establishment of each introduced taxon. Plants are listed in taxonomic order according to Fernald (1950). Several taxa were transplanted as whole plants, others were introduced by planting or broadcasting seed and others such as the Willow and Red-osier Dogwood were introduced as wands.

All stock was gathered from the wild in locales within 40 km of West Heights Pond. Whole plants and wands were transported in moist soil and were reintroduced immediately at West Heights. Seed which was planted was introduced within a few days of being collected. Seed for broadcasting was collected up to three weeks ahead of application by hand. None of the seed was treated. Dead stalks of Purple Loosestrife and Narrow-leaved Cattail which contained seed were pushed vertically into the soil in several locations around the pond margin. It was reasoned that seed would be released to the pond environment through natural processes.

The basic principle of the seed broadcasting technique was to make wild seed of desirable species, for which suitable conditions would exist, available immediately.

Numbers of plants or propagules were recorded for the transplanting and planting activities. The amount of seed for broadcasting was not measured but was described qualitatively.

Intentional introduction of marshland vegetation was confined to a band approximately 4 m wide around the pond, although wind may have spread seed a greater distance.

TABLE 1: INTRODUCTION METHODS BY SPECIES

PLANT SPECIES	INTRODUCTION METHOD(S)
Common Cattail	Transplant
Narrow-leaved Cattail	Seed
Giant Burreed	Transplant, seed broadcast
Water Plantain *	Seed broadcast
Broad-leaved Arrowhead	Seed broadcast (1979), transplant (1980)
Common Reed Grass	Transplant
Larger Blue Flag *	Transplant, seed planted
Sandbar Willow	Wands
Shining Willow	Wands
Bullhead Lily	Transplant (1979 and 1980)
Purple Loosestrife	Seed broadcast
Red-osier Dogwood *	Wands
Swamp Milkweed *	Seed planted & broadcast
Blue Vervain	Seed broadcast
Clotbur	Seed broadcast
Bur Marigold *	Seed broadcast

* Species present on the treated area prior to dredging.

Species arranged in taxonomic order according to Fernald (1950).

MONITORING METHODS:

Maps were prepared in the field which showed the location and number of plants or propagules introduced. Areas treated by broadcasting were also mapped. Thus, there was a basis for monitoring the success or failure of the 1979 introductions.

In September 1980, another mapping was completed which documented the numbers and variety of marshland and aquatic species which had become established. Brief visits to the study area were made during 1981 and 1982, at which time descriptive notes were recorded. In September 1983, another major mapping and counting effort was completed using methods similar to those employed in 1980. In June and July 1984 the site was visited to determine if any major changes in the vegetation complex had occurred since the previous year.

The 1983 inventory also involved preparation of species lists for the pond and littoral area, the backshore and the small pond to the south. The density of species within seven 0.25 m^2 quadrats was also determined along the SW margin of the pond where the greatest effort had been expended on introducing vegetation.

Numbers of study plants were determined only for the area where we introduced plant material. Numbers of species such as Cattail, Burreed and Bullhead Lily were determined by counting main stems or clumps.

The present analysis is a qualitative assessment of the fate of introduced taxa. Other data and observations (not presented in this paper) are cited to aid in interpretation.

As noted in Table 2, for species which were introduced using two or more methods, one of which was broadcast seed, it was often not possible to attribute numbers present to a specific introduction technique.

RESULTS AND DISCUSSION:

In September 1983 West Heights pond and littoral area supported 47 species and 66 species were found on the backshore area. Both of these areas had been extensively disturbed by dredging and by piling of dredge spoil, see Figure 2. Fifty-seven plant species were found growing in and around a small pond 30 m south of the study pond. Of these, 19 species were not present around the large pond.

Table 2 indicates changes in relative abundance of 16 pond and marshland species which we intentionally introduced following dredging. Six of these species (marked with an asterisk in Table 1) occurred prior to dredging or were growing around the small pond in 1983. None of the remaining ten species which were new to the area, dispersed from the north pond to the south pond during the last 5 years.

Discussion of plant introduction results is organized by technique.

FIGURE 3: INTRODUCED BURREED AND WATER PLANTAIN, 1980.

Transplant: The 22 Common Reed Grass plants which were transplanted appeared to have died in 1980. But in 1983 and 1984 four stalks of the species were found.

Survival of transplanted Common Cattail and Giant Burreed whole plants was excellent. Table 2 indicates that the 89 Burreed stems tripled in abundance by September 1980 and multiplied more, three years later. Figure 3 shows a Burreed stand in 1980. The Cattail stems more than doubled in number between 1980 and 1983. For both species vegetative propogation has been responsible for the increased stem group number.

Burreed and Cattail beds have assisted in stabilizing the shoreline and have provided food and cover for wildlife. Lamoureux (1957) and Yaich (pers. comm.) also report that these taxa perform these functions.

Arrowhead propagates by tubers and seed. Tuber or whole plant transplants are the recommended introduction methods for Arrowhead (Lamoureux 1957, Yaich pers. comm.). Experiments in 1978 proved that whole plants could be successfully transplanted to West Heights Pond. These plants were presumed buried during dredging. Seed was scattered in autumn 1979 and resulted in the Arrowhead patches present in July 1980. Extensive patches of Arrowhead present in 1981 along the southern end of the dredge area are thought to have become established from seed.

Bullhead Lily was also introduced as a whole plant. Introductions in 1979 failed because the bouyant roots floated free from the bottom. During 1980 fourteen more were planted into heavy clay soils. These plants have flourished and spread vegetatively.

Wands: Three species: Red-osier Dogwood, Sandbar and Shining Willow were introduced as wands which were stuck in moist soil around the pond margin. Approximately one-third of the Willow wands were flourishing in 1983. Many which did not survive had been broken by children. The Dogwood wand

TABLE 2: SPECIES ABUNDANCE AT INTRODUCTION, IN 1980 AND 1983

Method and Species	Amount Introduced		Total Number Present	
	Nov. 1979	Sept. 1980	Sept. 1980	Sept. 1983
Transplant				
Common Cattail	39	0	42	91
Giant Burreed	89	0	323	583*
Broad-leaved Arrowhead	0	2	29*	300+*
Common Reed Grass	22	0	0	4
Larger Blue Flag	12	0	10*	3*
Bullhead Lily	15	14	14	23
Wands				
Sandbar Willow) Shining Willow	75	0	33	28
Red-osier Dogwood	90	0	6	0
Seed				
Narrow-leaved Cattail	Thousands	0	0	0
Giant Burreed	Hundreds	0	hundreds	P
Water Plantain	Thousands	0	100+	33
Broad-leaved Arrowhead	Hundreds	0	29*	300+*
Larger Blue Flag	Dozens	0	10*	3*
Purple Loosestrife	Thousands	0	P	46
Swamp Milkweed	Hundreds	0	P	3
Blue Vervain	Hundreds	0	1	17
Clotbur	100±	0	7	25
Bur Marigold	Hundreds	0	84	204

NOTE: * Total number present results from transplant plus seed introductions.

P Present but no precise count.

introduction faired poorly, probably because the locations where they were placed became flooded once pond levels had stabilized. Bradshaw and Chadwick (1980) recommend hammering stakes of young Willow into damp soil, in spring, as a means of restoring quarries.

Seed: Narrow-leaved Cattail is the only species which failed to establish itself. Although Kadlec and Wentz (1974) indicate that wind-dispersed *Typha* seeds are responsible for quick establishment on newly exposed wet substrates, the seed introduction method was probably a poor choice for this species. Transplanting of root stock would probably have been more successful.

Burreed and Arrowhead seed was applied in 1979. Extensive beds of small individuals of both of these species were observed in 1981 along the east and west shores of the pond, south of the area which had been actively revegetated. Most of these patches had disappeared by September 1983. Muskrats and Mallards are suspected to have consumed these plants. Both plant species are valuable waterfowl and muskrat foods (Lamoureux 1957). Along the northern two-thirds of the pond Arrowhead abundance increased an order of magnitude between 1980 and 1983.

The remaining seven species were introduced using seed only. All of these species except Purple Loosestrife and Clotbur were present in the study area prior to dredging.

Water Plantain: Thousands of seeds were scattered on the soil surface. In 1980 over 100 plants were present. The mass of tiny white flowers on the left side of Figure 3 are those of Water Plantain. This species was particularly obvious along the northwest corner of the pond in 1980. Water Plantain persisted but it was not as obvious or abundant in 1983.

Water Plantain seed apparently must be submerged to induce germination and seed of this species is able to remain viable under water for years (Croker and Davis 1914). This species may become more abundant in future years if some of the original seed still remains in the seed bank.

Larger Blue Flag: This species was re-established in small numbers. Whether seed or transplanting was responsible is not clear. In 1983, it was difficult to locate among the tall grasses but at least three clumps were present. Since these plants require direct sunlight it may suffer from shading by grasses.

Lamoureux (1957) recommends propagation by rootstalk. Elsewhere we have been successful in establishing Iris versicolor by planting wild seed in the springtime.

Purple Loosestrife: This large colourful plant has become established from seed. In 1983 46 individuals of this species were present. It was growing in at least three locations around the pond in 1980 but a precise count was not made.

Swamp Milkweed: Although it was present in the seeded area in 1980 and 1983 the data available do not allow a precise determination of population trends.

Blue Vervain: One plant was observed in 1980, but 17 were present in 1983.

Clotbur: Approximately 100 seeds of this annual were collected and scattered on the dredge spoil in 1979. Seven plants were present in 1980 and 25 were present in 1983. This plant appears to tolerate trampling.

Bur Marigold (Bidens cernua): This colourful annual has more than doubled in abundance between 1980 and 1983. It was present in considerable quantities on the mud ring surrounding the pond prior to dredging.

Table 2 and quadrat data (not presented here) indicate that many of the species which were introduced by broadcasting seed are not numerically abundant. These species do, however, add diversity and colour to the pond margin vegetation complex.

SPECIES SUCCESSION:

Succession is used here in a broad sense to mean changes in plant species composition and abundance in the treated area.

The present discussion briefly addresses factors which are thought to have influenced succession of the marshland vegetation community at West Heights Pond during the past five years.

Seed Bank: Undoubtedly, the dredge spoil contained seed. The more widespread occurrence of certain rush and bulrush species after dredging may have resulted from germination of seed contained in the dredge spoil. Spreading of soil from wetlands has been recommended as a method for establishing vegetation on slurry impoundments (Yaich pers. comm).

Moist soil conditions trigger germination of seeds of several species of freshwater marsh plants present in seed banks (Smith and Kadlec 1983). Dormancy and after ripening in certain species will influence "recruitment" of those species into the West Heights plant community.

Seed Dispersal: A plant list for the small pond 30 m south of the treated pond has revealed that numerous wetland species have not spread from there to the large pond. Similarly, none of the ten species absent from both ponds before direct introduction to the large pond have spread to the south pond.

Brief inventories of wetland vegetation composition of four ponds within 2 km of West Heights have revealed that species such as Common Cattail, Sandbar Willow and Purple Loosestrife have existed within 1.5 km of West Heights but did not arrive there naturally. The literature indicates that wind, water, animals and man's activities play roles in dispersal of marsh plant seeds (Kadlec and Wentz, 1974).

Competition: We have no hard data on this factor but competition is expected among species arriving on the scene from various sources: human introduction, seed bank, weeds with effective dispersal mechanisms and so on. By 1984 Reed Canary Grass had become dense and undoubtedly choked out certain other species growing in upland sections of the west bank.

Kadlec and Wentz (1974) indicate that many annuals are adapted for widespread seed dispersal but that perennials will exclude annuals and subsequent competition among perennials will eliminate some species (pp. 196-197).

Shoreline Erosion. Wave action was responsible for local erosion along the pond margin early in the 1980s, before extensive vegetation growth became established. This caused several of the willow wand plantings to be washed away. Planting had been designed to minimize shoreline erosion and succeeded in this aim, in time. Perennial members of the followng families have dense and spreading root systems which stabilize substrates: Gramineae, Cyperaceae, and Typhaceae (Kadlec and Wentz 1974).

Soil Moisture/Water Levels: Since runoff and precipitation falling directly on the pond are the only sources of water for the pond, evaporation causes fluctuation in water levels. Consequently, shoreline soil moisture may vary from year to year and during a particular growing season.

Differences in soil moisture may be responsible for differences in plant communities on the spit during the last two years. For example Xanthium which was numerous on the spit in 1983, was absent in 1984 and Juncus balticus which dominated several quadrats was replaced by Soft Rush. Water Plantain appeared to be more numerous along the damp margins of the pond this July than it was during 1983 when conditions were drier and a narrow band of dry soil separated dense marginal vegetation from the water's edge. Receding water exposes moist soil which provides conditions conducive to seed germination in several freshwater marsh species (Smith and Kadlec 1983).

Trampling: The spit receives heavy foot traffic during dry years and paths are broken to the pond margin by children attempting to catch frogs and turtles. Willow saplings developed from wands, Burreed, Bidens and Xanthium have been observed to suffer damage from trampling. Trampling has not caused the elimination of any of the introduced species but may have been responsible for loss of certain individuals.

Muskrats, Mallards, Fish: Muskrat food piles which we examined contained Rush, Burreed, Spikerush and Cattail. Muskrat tunnels have been cut into the west bank of the pond, this was not noticed prior to pond dredging. It may be that an improvement in food availability since rehabilitation has increased muskrat population size.

In July 1984, three broods of Mallards were present on the pond. The young were observed feeding on pond margin vegetation. Mallards' diets are known to include a major vegetation component (Bellrose 1976). Ducks feeding in shallow water create turbidity which may have negative effects on plant growth.

During the past three years fish have become a prominent element of the pond ecosystem. Brown Bullheads grow large enough that they provide recreation for young anglers. Schools of Bullheads feeding in shallow areas create turbidity, just as ducks do. Since Bullheads are omnivorous (Scott and Crossman 1973) they may consume roots and seeds of aquatic plants.

Creating food and cover for fish and wildlife was one of our objectives, but we had not anticipated animals as a negative influence on the plants which we introduced. Others have concluded that waterfowl usually do not harm established stands although seedlings and newly invading shoots may be destroyed (Kadlec and Wentz 1974). We observed the loss of hundreds of Giant Burreed and Broad-leaved Arrowhead seedlings in the south end of the pond between 1980 and 1982. Krummes (1940) found that muskrats may "clean-out" established stands of favoured food plants.

In other settings the following factors may affect the success of marshland plant introductions: physical/chemical characteristics of the substrate, water quality and turbidity.

SUMMARY:

As noted by Bradshaw (1983) reconstruction of ecosystems is an environmental problem for which solutions are available and one to which ecologists have an important contribution to make.

Key findings of this study follow:

- Species selection is a key element of any revegetation plan. We were able to create an appealing vegetation complex in an urban residential setting by introducing certain showy species. Other more practical objectives such as shoreline and dredge spoil stabilization and provision of fish and wildlife cover were also achieved by introducing selected species.
- Revegetation under cool, moist late autumn conditions using local wild plant and seed stock was successful.
- Kadlec and Wentz (1974) and Wentz et al. (1974) should be referred to for details of marshland plant introduction techniques.
- Year to year variation in pond margin vegetation composition appears to be considerable. Water level fluctuation and shoreline soil moisture regimes are suspected of being responsible for these differences in plant communities.
- Introduction of Broad-leaved Arrowhead, Purple Loosestrife and Water Plantain by seed succeeded. This may be one of few locations where this has been attempted.
- Factors which we presume affected plant succession at West Heights include: seed bank; seed dispersal; competition; soil moisture/water levels; trampling; muskrats; mallards and fish.

- Ten plant species absent before dredging did not spread from the actively revegetated area to a small pond 30 m away, during the 5-year study period.
- Where marshland species which spread rapidly are required, perennials should be introduced in preference to annuals since the former will spread both vegetatively and by seed. Often seed production is unpredictable and unreliable and seeds may remain dormant for a time.

LITERATURE CITED

Bellrose, F.C. 1976. Ducks, Geese and Swans of North America. Stackpole Books. 544 pp.

Bradshaw, A.D. 1983. The Reconstruction of Ecosystems. J. Appl.Ecol. 20:1-17.

Bradshaw, A.D. and M.J. Chadwick.1980. The Restoration of Land. Blackwell Scientific Publications. Oxford.

Brown, D.M., G.A. McKay and L.J. Chapman.1980. The Climate of Southern Ontario. Environment Canada, Atmospheric Environment Service , Climatological Studies Number 5. 66 pp.

Crocker, W. and W.F. Davis.1914. Delayed germination of Alisma plantago. Bot. Gaz. 58:285-321.

Dance, K.W. 1979. The Urban Pond - Amenity or an Eyesore? Civic Public Works. June: 13-15, 44.

Dance, K.W. 1981. The Park Pond: A Plus or a Problem? Recreation Canada. No. 2:20-27.

Eleuterius, L.N. and H.A. McClellan.1976. Transplanting Maritime Plants to Dredged Material in Mississippi Waters. pp. 900-918. In: Proceedings of the Specialty Conference on Dredging and Its Environmental Impact. American Society of Civil Engineers, New York.

Fernald, M.L. 1950. Gray's Manual of Botany. D. Van Nostrand Company, New York, 8th Edition.

Kadlec, J.A. and W.A. Wentz.1974. State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural. Volume I: Report of Research. University of Michigan, Ann Arbor, pp. 231.

Krummes, W.T. 1940. The Muskrat: A Factor in Waterfowl Habitat Management. N.Am. Wildl. Conf., Trans. 5: 395-398.

Lamoureux, W.J. 1957. Aquatic Plants for Fish and Wildlife. Royal Botanical Gardens Tech. Bull. No. 1. Hamilton, Ontario.

Newling, C.J. 1981. Monitoring of Dredged Material Research Program Habitat Development Sites. Dredged Material Research Vol. D-81-1: 2-8.

Scott, W.B. and E.J. Crossman.1973. Freshwater Fishes of Canada. Fish. Res. Bd. Can., Bull. 184. Ottawa.

Smith, H.K. 1978. Habitat Development: An Alternative Method of Dredged Material Disposal. pp. 745-803. In: Proceedings of Symposium on Environmental, Socioeconomic and Regulatory Aspects of Coastal Zone Management. ASCE, New York.

Smith, L.M. and J.A. Kadlec. 1983. Seed Banks and Their Role During Drawdown of a North American Marsh. J. Appl. Ecol. 20:673-684.

Wentz, W.A., R.L. Smith and J.A. Kadlec. 1974. State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural. Volume II: A Selected Annotated Bibliography on Aquatic and Marsh Plants and their Management. University of Michigan, Ann Arbor. pp. 190.

Yaich, S.C. 1984. Slurry Impoundment Reclamation. Personal communication to K.W. Dance

APPENDIX 1: COMMON AND SCIENTIFIC NAMES OF INTRODUCED SPECIES

COMMON NAME	SCIENTIFIC NAME
Common Cattail	Typha latifolia
Narrow-leaved Cattail	Typha angustifolia
Giant Burreed	Sparganium eurycarpum
Water Plantain	Alisma triviale
Broad-leaved Arrowhead	Sagittaria latifolia
Common Reed Grass	Phragmites communis
Larger Blue Flag	Iris versicolor
Shining Willow	Salix lucida
Bullhead Lily	Nuphar variegatum
Purple Loosestrife	Lythrum salicaria
Red-osier Dogwood	Cornus stolonifera
Swamp Milkweed	Asclepias incarnata
Blue Vervain	Verbena hastata
Clotbur	Xanthium chinense
Bur Marigold	Bidens cernua

Nomenclature after Fernald (1950).

Abstract

Planning and Designing for Reclaimed Landscapes at Seton Lake, B.C.

Lawrence Diamond, B.C.S.L.A.

A recent program of recycling disturbed landscapes associated with hydro-electric projects has been undertaken by the Reservoir Lands Management Branch of B.C. Hydro. At Seton Lake, near Lillooet, sites include a large quarry, a series of borrow pits and a cut over portion of shoreline.

An overall masterplan includes phasing, trail and vehicular access and specific designs for view points, campgrounds and entrances. In addition, a planting strategy which emphasizes the use of leguminous and native vegetation as well as a grading approach for water retention has been evolved. The project's first phase examplifies a cost effective and compatable design for reclamation in a difficult terrain and climatic environment despite financial cutbacks.

Planning and Designing for Reclaimed Landscape: Seton Lake, British Columbia

Background

In 1971, B.C. Hydro and Power Corporation initiated a program of multiple-land use incorporating a range of public and private activities with energy generation and transmission. One result of this policy is the provision of public recreation at specific sites coupled with appropriate environmental protection and safety measures. In part, this mandate for public access is an attempt to alleviate an earlier perception of the Corporation as an aggressive consumer of land and water resources with consequential ecological and scenic disruption. During the last several years of financial exigency, B.C. Hydro has attempted to balance its engineering requirements with those of conservation and public benefit. Project cost effectiveness has become a paramount management considieartion.

In this context, the Corporation's Reservoir Lands Management Branch has developed several recreation areas on disturbed sites related to hydro power dams and impoundments. Its planning and implementation process includes identification of potentials and user requirements, master planning and design, construction and operation. Recreation areas at Shushwap Falls, Hayward Lake, Daisy Lake, Buntzen Lake and Seton Lake have been designated, and have received attention from this branch and its consultants. Site enhancement and rehabilitation have sometimes been necessary to assure human safety as well as to create recreational amenity. A design approach which emphasizes skillful regrading, careful plant selection, simple construction, inexpensive maintenance and the ability to tolerate intensive seasonal use is therefore required.

Project Work at Seton Lake

A 5 ha site is located approximately 320 km north of Vancouver at the east end of Seton Lake near Lillooet, B.C. A series of grassed and wooded terraces are separated by steep gravel slopes. A beach and an abandoned aggregate pit are also present. The interior dry belt climate is characterized by hot summers and cold winters with some snowfall. The property is associated with a dam (equipped with a fish ladder) a canal diversion and a 42,000 kw powerhouse which form part of the Bridge/Seton River generating system. The Duffy Lake Road which accesses the site is becoming an increasingly popular summer tourist route. Cayoosh Creek forms the southern property boundary. Benchlands above the stream are used by local residents and visitors for camping and picnicking, although few built facilities presently exist. The route to this area is through a former Ministry of Highways gravel operation.

The Corporation initiated a phased program of site planning for recreational use in 1980. Its first priority has been renovation of three specific areas within its parcel. Development at the beach site includes parking, picnic tables and comfort facilities. Regrading, installation of fencing and creation of a sloped and retained pathway from parking to the beachfront has all been completed in addition to the planting of shade trees related to a waterfront picnic area. A second stage of work entails implementation of a longer term trail as well as the creation of a major viewpoint and campground entrance accompanied by rehabilitation of the abandoned gravel pits. The challenges of site improvement have included coping with rough bare mineral soils, high summer temperatures with dessicating winds and infrequent rainfall, archeological sites requiring protection, plus an extemely limited budget. Therefore, careful grading has been combined with procedures for water retention, judicious use of topsoil, planting with nutrient enhancing leguminous cover crops and the introduction of tolerant native trees and shrubs. Impervious areas are limited to intersections with the Duffy Lake Road.

1. <u>The Seton Lake Viewpoint</u>

Located on the south side of Seton Lake above its confluence with the Seton River, the viewpoint provides extensive vistas toward Lillooet and the Fraser Valley as well as of the lake. The problems have been those of improving a rough gravel edge between the Duffy Lake Road and the site, providing increased slope stability between the viewpoint and the beach below, encouraging pedestrian access and circulation while protecting archeological middens and accommodating parking for tour busses and automobiles. As this site also allows direct views of the dam and the canal diversion, there is an additional opportunity to provide interpretive information about B.C. Hydro's overall use of the landscape.

The rough edge has been regraded to a 1:3 sloped facilitating planting and increasing its stability. Gravel from the pit (campground entrance area) below has been transported and utilized to provide a parking area and turnaround with proper cross-slopes provided for drainage. This material has also been used for pathways linking the parking area with viewpoints along the bluff edge. Barrier plantings are being installed below the perimeter pathway to discourage trespass and to increase stability. A new trail will link the upper viewpoint with the beach. An additional challenge has been protection and recognition of the important Indian Middens at this site. Both parking and foot paths have been routed to avoid these archeological locations and where feasible, the soil has been sculpted to better reveal their forms. Comfort stations and picnic facilities have been located in an adjacent grove of ponderosa pine trees. The requirement for bus and automobile parking at the viewpoint has been coupled with a new turnoff and entrance road to the beach below, enabling B.C. Hydro to better control visitor flow and surveillance. Incidence of vandalism has therefore been extremely low. Construction details for fencing, trails, signage and retaining walls (where necessary) have emphasized use of pressure treated timber plus locally available rock. While regraded slopes will be freshly planted with a cover crop mix and tolerant woody species, a developing meadow where most of the middens and some of the best views occur has been allowed to naturally colonize.

2. The Gravel Pit and Campground Entry

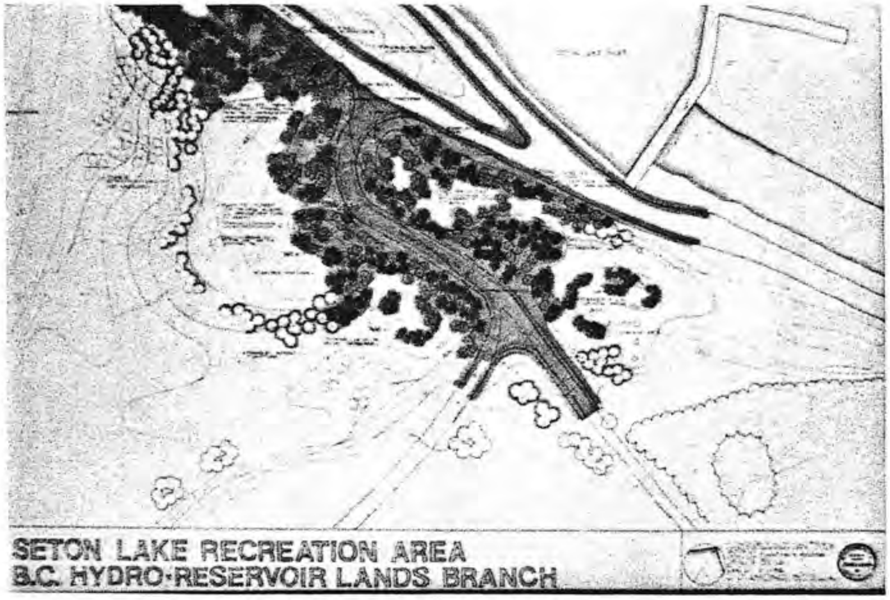
This exposed site is visible from the Duffy Lake Road as well as from the viewpoint on the upper terrace. A major problem at this location is the treatment of a very large steep gravel bank, approximately 50 meters in height. Partially the result of previous glacial activity, the slope has become increasingly barren and unstable as a result of undermining during aggregate extraction. A major challenge therefore is to increase its stability as well as its visual coherence with surrounding terrain.

An approach is being pursued which involves gradual rather than radical recontouring and a planting strategy which incorporates replenishment of the rough soil base as well as matchng ecosystems and successional phases. Overplanting with small trees and shrubs has been advised, as up to a 30% loss is possible. These trees and shrubs will be thinned at a later date. Two fields are being formed through regrading. One will accommodate informal play activities related to the picnicking and day use area at Cayoosh Creek while another will provide for larger recreation vehicle camping. The installation of shade trees related to these locations is therefore essential. During regrading a series of pockets to accumulate and retain moisture are being created on the shady side of recontoured slopes and berms. Topsoil and straw mulch are being utilized in conjunction with an early spring planting program.

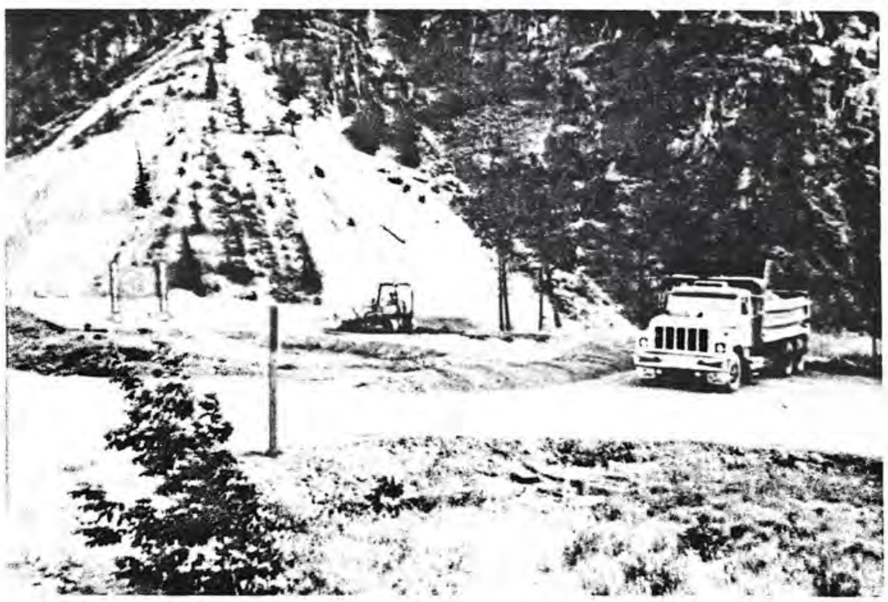
A custom seed mixture of legumes and grasses is scheduled for application on the bare slopes. Nitrogen fixing plants which have been recommended include white alsike clover, birdsfoot trefoil (a good slope performer) and perennial lupine. Recommended grasses are annual rye grass, alkalai grass and prairie velvet as well as aster. The herbacious perennial crown vetch provides vigorourous slope ground cover and chokes out undesirable weeds. The mix will vary with terrain and with proximity to tree and shrub plantings. For example, the grass content will be reduced adjacent to woody species. The steep exposed slope previously described will be hydroseeded, with additional planting installed once stabilized.

Research has been conducted into compatiable tree and shrub species for rocky, gravelly soils in this interior biogeoclimatic zone. Both ponderosa and lodgepole pine as well as douglas fir can, with a suitable mulching and early irrigation program be established. Trembling aspen, black cottonwood and Virginia cherry are among trees which will be considered, while ceanothus species, snow bush, soapberry and mahonia species will provide a shrub understory.

Since many decisions are being made on site by B.C. Hydro field personnel (with consultation with head office in Vancouver), a series of simple plans, sections and working details have been developed in addition to perspective sketches from various vantage points at both sites to guide layout crews. The extremely limited budget has not permitted an ongoing role for the outside consultant. Since startup in 1981, $350,000 has been



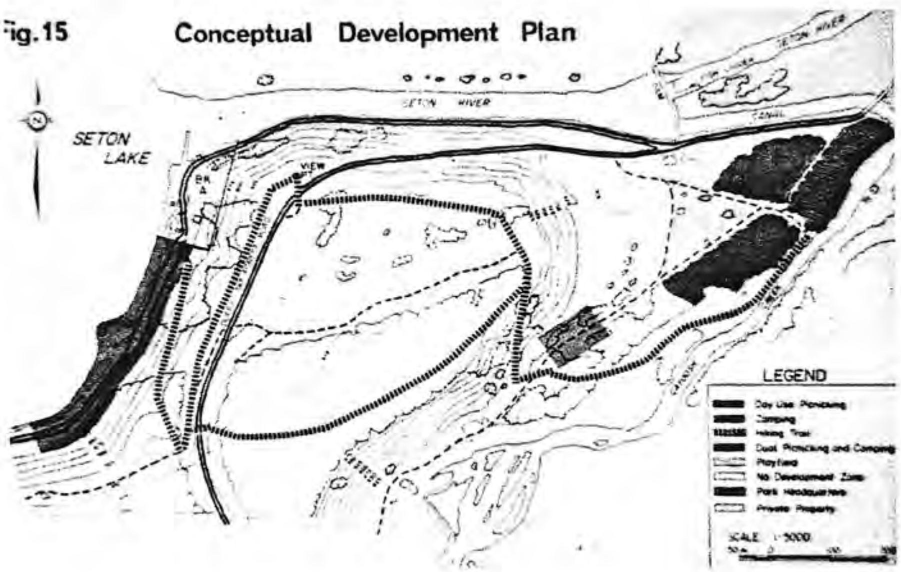
Reclamation plan for part of gravel pit which includes campground entry road.



Construction activity at viewpoint during 1983: grading.

Vista toward Lillooet and Fraser Valley from viewpoint above Seton Lake off the Duffy Lake Road.

Fig.15 Conceptual Development Plan



Conceptual Development plan including trail network. Both gravel pit and viewpoint are rehabilitation sites.

spent on rehabilitation and construction at both the viewpoint and campground entry, with an additional budget allowance for this fiscal year.

Conclusions

The Seton Lake project demonstrates the willingness of one large resource extractor to initiate the rehabilitation of a difficult landscape with resulting public benefit. It also illustrates the dichotomy between an optomistic long range plan executed during a time of more generous budgets and the reality of constraint. However, in a recent article for "Landscape", Robert Dorney (April, 1984) speaks out strongly against over reclamation. He argues that disturbed landscapes often serve as educational benchmarks and that in time, some of these can become important places ecologically. There is a tendancy, he adds, to manicure and sterilize such sites. Perhaps at Seton Lake the present condition of economic restraint will encourage a cautious approach with assessment of the success of each phase before subsequent expenditures.

This modest design project represents an important role for the landscape architect. It is ironic that in British Columbia, where the provincial economy is mostly dependent upon its natural resources, most professional work is concerned with urban developments many of which are in the Lower Mainland. Hopefully, the profession will find future opportunities to liase with both governments and the private sector to recycle and manage used landscapes for human enjoyment and new economic opportunities.

Acknowledgements

The writer would like to thank Mr. Colin Gurnsey and Ms. Mary Algar of B.C. Hydro's Reservoir Lands Branch for their cooperation. In addition, he would like to thank Professor Brian Holl of the Department of Plant Science and Professor J. Thirgood of the Faculty of Forestry at the University of British Columbia for their thoughtful advice.

References

Craig, D.H., Leiser, A.T. 1982. Biotechnical Slope Protection and Erosion Control. Van Nostrand Reinhold, New York.

Dorney, R.S. 1984. Reclamation: Somtimes the Cure is as Bad as the Disease. Landscape, Vol. 74, No. 3. Louisville, Ky.

Hosie, R. 1969. Native Trees of Canada. Queens Printer, Ottawa, Ontario.

Mitchell, W., Green, L. 1981. Identity and Interpretation of Ecosystems of the Western Kamloops Forest Region, Land Management Handbook 1-3. Ministry of Forests, Victoria, B.C.

Mitchell, W. 1979. Rehabilitation Seeding for Areas Denuded of Vegetation: Kamloops Forest Region, B.C. Ministry of Forests. Victoria, B.C.

Lyons, C.P. 1976. Trees, Shrubs and Flowers to Know in B.C., Wm. Dent and Sons. Vanocuver, B.C.

RECLAMATION OF THE URAD MOLYBDENUM MINE

Empire, Colorado

Larry F. Brown and Charles L. Jackson

AMAX Inc.

(Abstract)

The Urad Mine, located at an elevation of 10,400 feet near the Continental Divide in central Colorado, was operated from 1967-1974 by AMAX Inc. Mine related activities disturbed approximately 234 acres, of which two tailing deposition areas comprised 121 acres. Comprehensive reclamation was initiated prior to mine closure in 1974 and was completed in 1980.

Conventional revegetation techniques were implemented on typical disturbances while the tailing areas were reclaimed with the aid of three waste products. Mine waste rock was used to cap the tailing areas, and sewage and wood wastes were used to convert the rock into a rudimentary soil. The rock was revegetated and the vegetation is now permanent and selfsustaining.

INTRODUCTION

Mining has been the mainstay of the Woods Creek Valley for more than a century. The head of the valley is at the Continental Divide, about 50 miles west of Denver, Colorado. First, it was the quest for gold and silver that drew people to the valley. Then, when molybdenum was classified as a strategic metal by the U. S. Government during World War I, it was the valley's molybdenum mineralization which attracted the most attention. Molybdenum is used primarily as an alloying material in superior grades of steel.

Circumstances responsible for providing the label "Urad" are unknown, but Urad is variously reported to be an acronym for "Uranium Research and Development" or "Uranium Research of America Division". The search for uranium was fruitless as no ore grade uranium exists in this area. The moly orebody was first developed and mined by the Primos Exploration Company from 1914 to 1919. During World War II, the mine was purchased by the government and turned over to the Molybdenum

Corporation of America to operate. In 1963 AMAX Inc. purchased the property for $2 million. After spending nearly $30 million for exploration and development, AMAX put the mine into production again in 1967.

A modified block-cave system of underground mining was used to remove the ore from the deposit located inside Red Mountain. The Urad orebody contained approximately 14 million tons of ore at an average grade of about 0.33 percent MoS_2. The mining and milling rate was about 5,000 tons of ore per day, which represented about five percent of the free world production of molybdenum during the years AMAX operated the mine. The orebody was depleted and the mine closed in 1974 after producing about 48.5 million pounds of molybdenum in MoS_2 concentrate.

Conventional crushing and flotation milling circuits were utilized to process the ore. Nearly six pounds of MoS_2, containing approximately three pounds of molybdenum, were recovered from each ton of ore mined. The remaining 99.7 percent was predominantly composed of silica and was transported by water slurry to two tailing deposition areas. The water was then decanted from the surface of the tailing ponds and recycled back through the industrial mill water circuit.

CLIMATE

The elevation of mine property varies from 10,000 to 12,300 feet. Climatological data for the 16 years from 1965 through 1980 indicates the mean annual temperature to be 33^{o} F with maximum and minimum temperatures of 80^{o} F (August 1979) and -35^{o} F (January 1979) respectively. Approximately 45 to 60 consecutive frost-free days occur each summer. Total annual precipitation varied from 17.5 to 36.6 inches, averaging 24.3 inches. An average annual snowfall of about 200 inches provides most of the precipitation. No wind velocity data is available; however, it is estimated that maximum gusts might reach as high as 70 to 80 miles per hour.

VEGETATION

The bottom of the valley, which is that portion most affected by mining activities, is in the subalpine zone of vegetation. The uppermost part of Red Mountain is alpine. Naturally occurring climatic vegetation of the valley is the Englemann spruce (Picea engelmannii) - subalpine fir (Abies lasiocarpa) forest common to the subalpine zone of the Rocky Mountains.

DISTURBANCES IN THE VALLEY

The upper end of the valley was strip-cut logged as recently as 1962, and major logging occurred during the 1920's. The lower northwest facing side of the valley suffered a severe forest fire during the 1870's or 1880's. Some of the damage was reforested, but regrowth has been extremely slow demonstrating the extreme harshness of the habitat.

Avalanches, a major problem in the valley during mining, are a continuing source of natural disturbance. There are 17 avalanche runs, 12 of which are classified as major, in the three-mile long valley.

Each company that previously operated Urad did so in a manner somewhat similar to AMAX; however, the scope of their operations was not as large as the AMAX operation. During World War I, tailing was discharged directly into the creek. During World War II, tailing was contained in a pond, however, there was no seep-water or settling pond to contain discharge and erosion into the watershed. AMAX constructed a mill water pond below all disturbances which allowed recycle of seep water and a separation of natural runoff water from the industrial circuit.

The following is a breakdown of the acreages of disturbance at Urad.

Disturbance	Acres
Upper Reservoir	36
Lower Reservoir	20
Upper Tailing Area	78
Lower Tailing Area	43
Mine Yard and Refuse Area	17
Borrow Areas	22
Mine Waste on Red Mountain	5
Glory Hole	13
TOTAL	234
(Plus 15 miles of road)	

The overall goal in reclaiming disturbances was to initiate and accelerate the natural continuous trend toward recovery by stabilizing and revegetating. Conventional revegetation techniques were implanted on the more typical disturbances such as borrow pits and roads. The two tailing ponds presented the most difficult and interesting set of reclamation problems, and the problems were compounded by the high altitude. Therefore, most discussion is limited to reclamation of the tailing areas only.

TEST PLOTS

Sulfide tailing have been successfully revegetated (Peters 1970, 1974, 1978; Michelutti 1974; Young 1969) but require many years of maintenance. Research in establishing vegetation directly on tailing at the Climax Mine (Berg and Barrau, 1975) indicated various problems such as acidification, blowing and drifting of tailing, and physical instability in the root zone for trees during high winds.

A 4 X 4 factorial experimental design using various application rates of sawmill wastes and sewage sludge (with two replications) was implemented in the spring of 1974 on both bare tailing and waste rock capped tailing (Figure 1). The design crossed three application rates of sewage (5, 10, and 20 tons per acre) and one rate of NH_4NO_3 (60 pounds of nitrogen per acre) with two rates of sawdust (4 and 8 tons per acre), one rate of wood chips (20 tons per acre), and a control. All plots were uniformly treated with 300 pounds of P_2O_5 per acre and received light daily irrigation the first season only.

Development Waste Rock vs. Tailing Growth Media

Since the source of the rock was 4,000 to 5,000 feet underground, it was essentially a sterile growth medium. The major problems to be overcome with the rock were the lack of organic matter and nitrogen. Acidification was not a potential problem with the rock because of its coarseness. Sterility and acidification are both problems when using tailing as a growth medium.

5t/aSS 20t/aWC	20t/aSS 20t/aWC	10t/aSS 20t/aWC	60#/aN 20t/aWC
5t/aSS	20t/aSS	10t/aSS	60#/aN (Control)
5t/aSS 8t/aSD	20t/aSS 8t/aSD	10t/aSS 8t/aSD	60#/aN 8t/aSD
5t/aSS 4t/aSD	20t/aSS 4t/aSD	10t/aSS 4t/aSD	60#/aN 4t/aSD

Figure 1: Experimental design for testing the feasibility of utilizing wood waste and sewage sludge to aid revegetation of fragmented rock and tailing growth media. SS=sewage sludge, SD=sawdust, WC=wood chips, N=nitrogen, t/a=tons per acre, #/a=pounds per acre. All values are dry weights.

The test plots indicated that the fragmented rock is actually a much better growth medium than tailing. The major attribute is that the rock cap eliminates potential tailing acidification problems by slowing the rate of oxidation and providing a capillary barrier to upward migration of water. The rock also stabilizes the tailing and eliminates the problems of blowing and drifting encountered when revegetating tailing.

Plant/soil water relations of tailing are actually good and one would expect the rock to be too coarse to hold sufficient water to sustain plants. However, rock is the ideal mulch. Very little moisture is lost by evaporation from the surfaces of rocks, thereby conserving water in the root zone which encourages vegetative growth between rocks. The rock also provides a stable (solid) root zone for trees. Trees grown in tailing might be uprooted by high winds after growing to a height of five or six feet.

SOIL BUILDING AMENDMENTS

Evaluation and extrapolation of the results of the test plots, consultant advice, literature review, and experience led to the conclusion that the most practical and beneficial combination of amendments to be used on the fragmented rock was an application of 20 dry weight tons per acre of wood chips and 30 dry weight tons per acre of sewage sludge. Metropolitan Denver Sewage Disposal District No. 1 and the Forest Products Division of the Koppers Company, Inc. (Fraser, Colorado) cooperated in providing respectively 4,200 dry weight tons of anaerobically digested sludge and 24,000 cubic yards of wood chips. The wastes were provided free of charge, however, AMAX had to arrange and pay for transportation. Haulage distances were 87 miles for sewage and 24 miles for wood chips.

Applying 50 tons of organics to the rock is a giant step toward the construction of a mature soil which is prerequisite to achieving self-sustaining vegetation. It was initially hypothesized that the application of organics, along with good vegetative growth maintained through the years with inorganic fertilizers, should provide a soil of sufficient maturity to sustain vegetation within 15 to 20 years (Brown 1974 and 1976).

The process has occurred much more rapidly than anticipated. The vegetation has been maintenance fertilized only once, in 1979. In retrospect, the vegetation was probably permanent and self-sustaining as soon as it became established. Even so, the vegetation may receive one or more additional applications of maintenance fertilizer to maintain its vigor.

In addition to being a source of organic matter, the reason for applying wood chips can be illustrated with a halflife analogy. In the harsh climate at this elevation, the half-life of nitrogen in sewage sludge might be from two to five years. Thirty tons of sewage contains roughly 1,200 to 1,800 pounds of nitrogen. If half of that were to become available for plant use within two years, the result would be similar to applying 300 to 450 pounds of nitrogen per acre per year to vegetation requiring only about 60 pounds of nitrogen per acre per year. This would be a gross overapplication of nitrogen except for the presence of wood chips. Wood chips have a high carbon-to-nitrogen ratio (about 90 to 1). Soil organic matter, the desired product, has a carbon-to-nitrogen ratio of about 10 to 1. Microbial decomposition of the wood, therefore, requires relatively large quantities of nitrogen and uses the excess nitrogen from the sewage to form humus. Thus, much of the excess nitrogen is immobilized and retained in the soil for future plant use.

The sewage and wood chips complement each other. Using the two together allowed the efficient application of a significant quantity of nutrients and organic matter at one time. The potential for severe nitrogen immobilization was monitored, but never materialized probably because of the low rate of microbial decomposition controlled by the cold climate.

ROCK COVER

Haulage of the fragmented rock from the Henderson Mine began in July, 1974. The purchase of seven trucks and a D-8 dozer was necessary to initiate the program. Approximately 1.5 million tons of rock were hauled and spread on the tailing dam faces and surfaces to ensure stability.

Water is the most significant destabilizing threat to tailing dams. Drainage of water in the tailing dam faces was assured by the placement of a five-foot depth of graded coarserock contiguous with the face to provide a drain blanket. Subsurface water reaching the face of the dams is removed by these rock drains. To complete the stabilization of the dams, ungraded fragmented rock was benched up the faces at a minimum depth of ten feet. Piezometer wells were installed in the crests and faces of the tailing dams to monitor the phreatic line.

The surfaces of the tailing areas were covered with three feet of rock. Attempts were made to utilize the rock covering to break the flat contour of the tailing areas. Hillocks and ridges were constructed with the rock while keeping in mind the importance of cold-air drainage to plant growth. The amount of this type of landscaping possible was dependent on the stability of the tailing. The stability of the underlying tailing would not allow construction of hillocks in excess of 10 to 12 feet high.

TAILING RECLAMATION SEQUENCE

The sequence of revegetating the tailing areas was:

1. Cover with waste rock.
2. Landscape with rock (small hills to break the flat contour).
3. Spread P_2O_5 and wood chips.
4. Rip wood chips and P_2O_5 into the surface (by dozer).
5. Spread sewage sludge (manure spreader).
6. Seed with grasses.

7. Scatter dead timber onto the surface.
8. Irrigate (1st growing season only).
9. Plant trees and shrubs (seeds, transplants and seedlings) during second growing season.
10. Maintenance fertilize with inorganic fertilizers.

Dead timber was cleared from areas adjacent to the tailing ponds. The trees were scattered on an area after seeding to provide small mammal habitat, shelter vegetation from the wind, and improve the aesthetics.

Early in the project, trees and shrubs were planted in an area at the same time grass was planted. Beginning in 1977, trees and shrubs were not planted in an area until the grass was one year old. It was felt that protection from the sun and wind, provided by the grasses, would increase the survival rate of trees and shrubs.

Another deviation from the reclamation sequence occurred in 1979 when the last 18 acres of unvegetated tailing surface were to be treated. This patch was at the upper (fines) end of the upper tailing pond and was still not adequately dewatered to support heavy equipment in the summer. (Rock was placed on these areas in the winter when they were frozen and could support the weight.) Because heavy equipment could not be supported, it was necessary to distribute the wood chips and sludge manually. Consequently, the coverage of organics was lighter, and they were not ripped into the rock. The grass cover on the 18-acre patch is doing well despite the lack of ripping.

REVEGETATION

Grasses are the foundation of the revegetation program, however, 44,000 tree and shrub seedlings have also been planted at Urad.

Grasses

Revegetation research has been ongoing at the Climax Mine near Leadville, Colorado since 1965. Initially, a grass-seed mixture was chosen for use as a result of the high-altitude species adaptation research done at the Climax Mine by Dr. W. A. Berg of the C.S.U. Agronomy Department. The initial seed mixture contained eight herbaceous species. Additional species and changes in the proportions have occurred as a result of research and seed availability (in quantity) from suppliers. The present seed mix is listed in Table 1.

Additional species adaptation research has been ongoing since 1974. The objectives of the project are to select varieties of species for their adaptability, possibly cross them, and produce seed sources for high-altitude revegetation programs. Native species have been included when possible. Approximately 62 species represented by 136 accessions have been planted at 22 different high-altitude sites in the central mountains of Colorado (Cuany 1982). The Climax and Urad mines are two of the sites. The project is being funded through the High Altitude Revegetation Committee by donations from government and industry (Cuany 1982).

Table 1: Climax Seed Mix

Scientific Name	Common Name-Variety	Percent by Weight
Agrostis alba	redtop	3
Alopecurus arundinaceus	creeping foxtail	5
Alopecurus pratensis	meadow foxtail	5
Astragalus cicer	cicer milkvetch - Cicer	4
Bromopsis inermis	smooth brome - Manchar	15
Dactylis glomerata	orchard grass	5
Festuca arizonica	Arizona fescue	4
Festuca ovina	hard fescue - Durar	8
Festuca rubra	red fescue - Pennlawn	8
Phleum pratense	timothy - Climax	5
Poa ampla	big bluegrass - Sherman	3
Poa compressa	Canada bluegrass - Reubens	2
Poa pratensis	Kentucky bluegrass - Troy	3
Secale cereale	rye - Balboa	20
Trifolium repens	white Dutch clover	10
TOTAL.		100

Notes: 1. Legumes were inoculated using the Rhizo-kote method.

2. This mixture was seeded at the rate of 50 to 60 pounds per acre, depending upon the severity of the habitat.

3. Secale cereale was included to provide fast cover and serve as a nurse crop for the establishment of the perennials.

Trees and Shrubs

Potted evergreens, shrubs, and aspen seedlings purchased from various nurseries were used in the tree/shrub revegetation. Six species of trees were used. They were Engelmann spruce, lodgepole pine, bristle cone pine, limber pine, subalpine fir, and aspen. Eighteen species of shrubs native to the area were used. Survival plots of 100 seedlings were installed to determine survival rates. Evergreen seedling survival rates ranged from 50 to 60 percent.

Holes for trees and shrubs were dug by pick and shovel, the tree and shingle were implaced, the hole was backfilled, the ground was compacted by foot, and a gallon of water was poured on the ground around the tree to further compact the soil and eliminate air spaces. It was not possible to use mechanical equipment to dig the holes. The shingle slats serve to protect evergreen seedlings from the sun and wind. Aspen were not provided with this protection. The only maintenance is inorganic fertilizer applied jointly to plant materials and grass.

A biological paradox was first observed in 1979. Numerous volunteer aspen and willow seedlings began emerging on a portion of bare (unripped, unamended) waste rock capping the upper tailing pond. Aspen seedlings are extremely rare in nature, and germination conditions on this bare, exposed, and sterile surface would appear to be prohibitive. The fact that anything but the most drought hardy species will germinate under such conditions indicates we have a lot to learn about the process. The habitat is the antithesis of what is normally considered good aspen habitat, yet the seedlings are thriving with each successive year.

This observation prompted the broadcasting of aspen seed. In the spring of 1980, small aspen trees and branches from larger aspen with apparently ripe seed were cut and the seed distributed by shaking and scattering the branches on the ponds on a windy day. The procedure was repeated over a two-week period to increase the probability of using ripe seed. It may be years before the results of this trial are evident.

A tree fertilization test was initiated in 1981 by planting fertilizer tablets (21 grams each, 20-10-5, NPK) with lodgepole pine and Engelmann spruce. Again, because of the very low growth rates at this elevation, the results of tests such as this may not be evident for years.

To add aesthetic variety to the vegetation, fifty threefoot-tall blue spruce (Picea pungens) in 20-gallon tubs were planted in topsoil on the tailing surfaces. The trees were placed on the leeward side of the small hills on the tailing surfaces for wind protection. Trees were planted in groups of four to provide mutual protection in the harsh conditions. Water (1-2 gallons) was poured on the ground surrounding each tree after planting to pack the loose backfill. A one-foot deep cover of wood chips was spread around the trees to reduce evaporative loss. To date, approximately 50 percent of the trees are surviving.

Several pounds of lodgepole pine seed (at 90,000 seeds per pound) were distributed at Urad through the years. Results of these efforts are also thus far inconclusive. It may take years for the seed to germinate, and then seedlings are barely discernible for an additional one to four years.

Willows were planted in suitable wet spots at Urad. Besides the purchase of potted materials, willow transplants were utilized. Willow cuttings also were produced in-house by potting in spring and/or fall, nurtured for a growing season, and outplanted. Willows have been particularly successful in the harsh environment. Successful in this context means they survive and thrive, but remain decumbent in the harsh windblown environment.

Mycorrhizal Fungi Research

AMAX funded a research project through Colorado State University (Grossnickle 1978 and 1983) to test mycorrhizal fungi inoculated evergreen seedlings for use on the waste rock. Fungi were cultivated separately and added to the potting medium. Mycorrhizal fungi effectively serve to increase the surface area of roots thereby increasing the capacity for intake of nutrients and water. The research indicated that fungal inoculation alone is not the hoped for panacea for increased seedling growth and survival on mine waste. Environmental extremes of temperature and moisture stress may be so limiting as to effectively nullify possible positive effects from fungal inoculation.

Forbs

Various species and mixtures of wildflower seed were used. The bulk of the seed was obtained from supply firms, but company personnel gathered seed on occasion. Forbs supply an element of vegetative diversity to the overall landscape. Although not dominant, the frequency and diversity of forbs appear to be increasing with time.

Various aquatic species were also planted in shallow, water-filled depressions on the tailing surfaces. Species tried were cattail roots, sago pondweed tubers, wild celery tubers, and some wild-rice seed. These trials appear to have been unsuccessful.

VEGETATION AND SOIL MONITORING

Vegetation and soil monitoring were conducted in 1979. Dr. M. J. Trlica (CSU Range Science Department) was retained to investigate plant species, frequency, cover, diversity, and production of revegetated areas, the nutrient regime of the amended waste rock through time, and heavy metal uptake by vegetation growing in the rock.

Vegetative Measures

Comparisons were made between the vegetation on the rock capped tailing surfaces, a revegetated borrow pit area, a revegetated road cut, and a control spruce/fir complex that burned circa 1879. Results of the studies indicate that stands are well established, productive, and effectively controlling wind and water erosion. Cover on the tailing ponds equals or exceeds that of the native community. The frequency of occurrence on the tailing had increased with each season by 1979, but was not yet equal to that of the control. Production on the tailing areas was more than double the production of the control.

Reclaimed areas were more diverse than the control because of the combined numbers of planted and invading species, and diversity was increasing with time. Dominant species on the reclaimed areas are smooth brome, hard fescue and timothy. If water and ample-to-excessive nitrogen were available on a continuous basis, these species would continue to dominate. However, inorganic fertilizers have been sparingly applied to encourage native invasion even though this results in lower cover and production values.

Nutrient Regime of Amended Waste Rock

An attempt is being made to monitor the soil building process. Periodically, the nutrient regime of the revegetated rock is measured to determine trends of chemical constituents through time. In 1979, samples were taken from portions of the rock capped tailing areas which had been seeded from 1975 to 1979 and compared to each other and to literature values of natural soil. Two to three years after the addition of amendments and the establishment of vegetation, there was some decline in conductivity, nitrate nitrogen, potassium, and zinc, probably due to leaching and plant uptake. Nitrogen is limiting as would be expected. Potassium levels are moderately high; iron, copper, zinc, phosphate, and manganese are high; and calcium and magnesium are marginally low in the growth medium. The pH is slightly alkaline and salts are not excessive. By 1979, it appeared that growth and development of plants on the crushed rock had only minor effects on the characteristics of the growth medium.

Heavy Metal Uptake by Vegetation

Smooth brome and white Dutch clover were sampled to determine if heavy metals were being concentrated by vegetation on waste rock covering the Urad tailing. In addition, it was felt that older, deeper-rooted plants might concentrate more heavy metals than younger, shallower-rooted plants. However, stands of vegetation planted in 1975 contained lower concentrations of arsenic and molybdenum than stands planted in 1977. The remainder of the elements tested showed no significant change with time. It is not known whether older plants are more selective in uptake of molybdenum and arsenic or that perhaps the elements became less available as the growth medium aged. White Dutch clover had significantly higher concentrations of aluminum, zinc, iron, molybdenum, cyanide, and fluoride than smooth brome.

Although there were higher concentrations of some elements in the growth medium compared to concentrations reported for soil, no plant toxicity has been observed. Normal grazing by wild ruminants on the revegetated ponds should not present a toxic uptake problem.

STRUCTURE DISMANTLE AND FLOOD CONTROL

Structures at the mine site included a mill, offices, warehouse, conveyors, shops and pumphouses. Equipment was removed from the structures and distributed as needed to other AMAX facilities. Removal of most structures was then contracted to a salvage company. The foundations were blasted, covered with waste rock and revegetated using the same process as that used on the tailing ponds.

Flood protection was a major aspect of the reclamation program. In 1978 and 1979, the company constructed a 12-foot by 12-foot box-culvert bypass of the lower tailing pond and two water retention dams. This flood storage/bypass system supplements the original water bypass system constructed in the mid1960's and provides protection for the tailing areas against the "probable maximum flood". The level of the upper reservoir, originally constructed to supply industrial mill water, was also lowered to provide flood water storage. The new outlet structure was situated to ensure sufficient water in the reservoir to maintain it as a public fishery.

COSTS

The cost to reclaim the mine was approximately $6.5 million, more than three times the $2 million AMAX paid for the property in 1963. An additional $0.5 million may be required for long-term maintenance of all aspects, i.e., property, roads, water management, and vegetation.

One way to calculate the cost per acre for reclamation would be to divide $7,000,000 by the 234 acres with a resultant cost of about $30,000 per acre. However, as is indicated by the cost breakdown presented below, Urad was unique. For example, there were unusual expenditures of approximately $3 million on flood control and $2 million to put waste rock from an adjacent mine to beneficial use at Urad. Actual costs for revegetaton were about $2,500 per acre.

Approximate costs for the Urad reclamation project are as follows:

Rock covering	$2,200,000
Flood control	2,900,000
Revegetation.	600,000
Management, protection, research, taxes, insurance, etc.	800,000
Long-term maintenance (contingency) .	500,000
TOTAL	$7,000,000

EVALUATION

Reclamation of the Urad Mine was initiated in 1974 and essentially completed in 1980. The approach toward reclamation of the tailing deposition areas was unique and somewhat experimental. The result was a better quality vegetation than originally anticipated which reached a permanent and selfsustaining status sooner than expected. The overall cost was high because of unique circumstances, mainly involving flood protection. The cost per acre for revegetation was within the normal range of costs. The key ingredient in the overall reclamation process was the mine waste rock. The key ingredient to rapidly established good quality vegetation was sewage sludge; and, the use of sewage was very cost effective. Hauling sewage 87 miles (one-way) cost less than purchasing equivalent quantities of inorganic fertilizer.

No statistical analysis have been performed on the plots; however, thirty tons of sewage and twenty tons of wood wastes per acre may have been excessive. Thirty tons of sewage was not one of the tested rates on the plots. Thirty tons per acre were used because, in the early stages, vegetation in the 20 ton plots looked better than the vegetation in the 10 ton plots, and vegetation in the 20 ton plots appeared sparse in itself. Thirty tons may be better in the very long term. However, current observations of the original test plots indicate little or no difference between the 10 and 20 ton treaments. It has long since been obvious that, at high altitude, three "normal" growing seasons are required for a stand of grass to mature.

Present observations of original test plots also do not indicate significant differences between wood wastes vs. no wood wastes. The rationale was explained in detail earlier, i.e., that wood wastes provided additional organic matter and a storage mechanism for excess nitrogen from the sewage. That rationale cannot be detrimental in the long term, but the cost effectiveness is questioned.

As indicated earlier, the revegetation procedure on the tailing ponds cost approximately $2,500 per acre. If similar results could have been attained with no wood wastes and only 10 tons of sewage per acre, the cost per acre for revegetating would have been cut in half, providing an overall savings of about $150,000. However, another few years of observation is necessary before definite conclusions can be drawn.

AWARDS

AMAX has received several awards for its environmental efforts. Those specifically related to the Urad Mine are:

National Gold Medal Award, presented by the Sports Foundation Inc. in 1969 for outstanding achievement in the fight against water pollution.

First Annual Business Citizenship Award, presented by Business Week Magazine in 1969 for preservation of the natural environment.

Citation presented by Colorado State Water Pollution Control Commission in 1970 for prevention of pollution to the waters of the State.

Certificate of Appreciation, presented by the Colorado Wildlife Commission in 1981 for opening lands at Urad Reservoir to public fishing.

National Environmental Industry Award for Excellence, presented by the President's Council on Environmental Quality in 1981 for outstanding leadership in the application of advanced environmental technology for reclamation of the Urad Mine.

LITERATURE CITED

Berg, W.A., E. M. Barrau, and L. A. Rhodes 1975. Plant growth on acid molybdenum mill tailings as influenced by liming, leaching and fertility treatment. The Ecology of Resource Degradation and Renewal, 15th Symposium of the British Ecological Society, July 1973, pp.207-222.

Brown, L.F. 1974. Comprehensive plan for land reclamation and stabilization at the Urad Mine. AMAX Inc., 39 pp.

Brown, L.F. 1976. Reclamation at Climax, Urad, and Henderson Mines. Mining Congress Journal, April, pp.42-43 and 49-51.

Brown, L. F. 1982. Reclamation and topsoil use. Mining Congress Journal, June, pp.48-52.

Cuany, R. L. 1982. The High Altitude Revegetation Committee - who we are and what we do. Proc. High Altitude Revegetation Workshop No. 5, R. L. Cuany and J. Etra eds. C.S.U. Water Resources Res. Inst. Info. Series No. 48, pp.12-28.

Grossnickle, S.C. 1978. Revegetation of a high altitude mine site with the use of mycorrhizal conifer seedlings. M.S. Thesis, Colorado State University, 149 pp.

Grossnickle, S.C. 1983. Growth, development, and water relation patterns of conifer seedlings on a high elevation mine site. Ph.D. Thesis, Colorado State University, 252 pp.

Michelutti, R. 1974. How to establish vegetation on high iron-sulfide mine tailings. Can. Mining J., Oct., pp.51-58.

Peters, T.H. 1970. Using vegetation to stabilize mine tailings. J. of Soil and Water Conservation, Mar-Apr, pp.65-66.

Peters, T.H. 1974. New developments and thoughts on INCO's tailing revegetation program. Proc. Mineral Waste Stabilization Liaison Committee Meetings, Hot Springs, Ark., 7pp.

Peters, T.H. 1978. Inco Metals reclamation program, Can. Mining and Met. Bull., Dec., pp.1-3.

Young, C.A. 1969. The use of vegetation to stabilize mine tailings areas at Copper Cliff. Can. Mining J., June, pp.43-46.

EFFECTS OF REPLACED SURFACE SOIL DEPTH ON RECLAMATION SUCCESS AT THE JUDY CREEK TEST MINE

Alan J. Kennedy

Esso Resources Canada LTD; Oil Sands, and Coal Dept., 237 - 4 AVE S.W., Calgary, Alberta T2P OH6

ABSTRACT

The effects of replaced surface soil depth on establishment of seeded grass/legume vegetation and lodgepole pine (*Pinus contorta*) was investigated on study plots at the Judy Creek Test Mine from 1979 to 1983. Nine plots representing replicates of three treatments of soil depth (0 cm, 30 cm and 70 cm) were established in a randomized block design. A grey luvisol surface soil with mixed A and B horizons was placed over a till subsoil. The till material, based on pre-study analysis, showed no inhibitory properties to plant growth.

Results of five years of study indicate that vegetation cover was continually higher on the 0 cm treatment than on either the 30 cm or 70 cm treatments. Differences in total cover were most pronounced during the first three years of study and decreased with succeeding years. The Alfalfa component of the revegetation seed mixture was the major contributor to total cover on the 0 cm plots due to the slightly alkaline soil conditions on this treatment.

An opposite relationship between soil depth and reforestation success was observed. The 0 cm treatment afforded lower survival and reduced growth than either the 30 cm or 70 cm treatments. Reduced survival of pine on the 0 cm treatment is attributed to the greater herbaceous cover which resulted in competition between tree seedings and vegetal species and increased the potential for small rodent-caused mortality. Reduced tree growth on the 0 cm plots is related to lower soil moisture and pH and a tendency for compaction of the till.

INTRODUCTION

Considerable attention has been placed on the topic of optimal soil depth replacement for adequate reclamation. For example, the United States Bureau of Mines recently supported a large scale research study to determine optimal soil depth replacement on mined lands within the Northern Great Plains. (Colorado School of Mines, 1983). Results from this study indicate that soil depth requirements appear to depend primarily on the quality of the spoil to be covered.

Spoil materials may be unsuitable for adequate plant growth for a variety of reasons including low fertility, droughtyness, and high salt levels. Sodic spoil materials are particularily difficult to revegetate due to physical instability and undesirable properties related to water infiltration, movement and retention. (Doering and Willis, 1975).

Several research studies have evaluated the effectiveness of applications of various thicknesses of "topsoil" possessing characteristics suitable for plant growth to sodic mine spoil. Pole et al. (1979) grew Spring wheat and corn on sodic spoils covered with 5 to 61 cm of suitable "topsoil". These authors concluded that "topsoil" 61 cm in depth provides the greatest yields but 30 cm is often as good. Sandoval and Gould (1978) reported that productivity of Crested wheatgrass grown on 30 cm of good quality surface soil progressively decreased during four years of study. This decline in productivity suggests that a deterioration in surface soil quality may be expected through time.

In Alberta, quidelines provided in Alberta Agriculture (1981a) indicate that soil material suitable for plant growth should be stockpiled and respread on the surface following disturbance. Various depths of soil replacement are suggested depending on the soil region in which the reclamation is carried out. For Northern forest soils two lifts of soil are suggested; an upper lift (30cm) of surface material (organic and A horizons), and a lower lift (170 cm) of subsurface material (lower horizons and parent material).

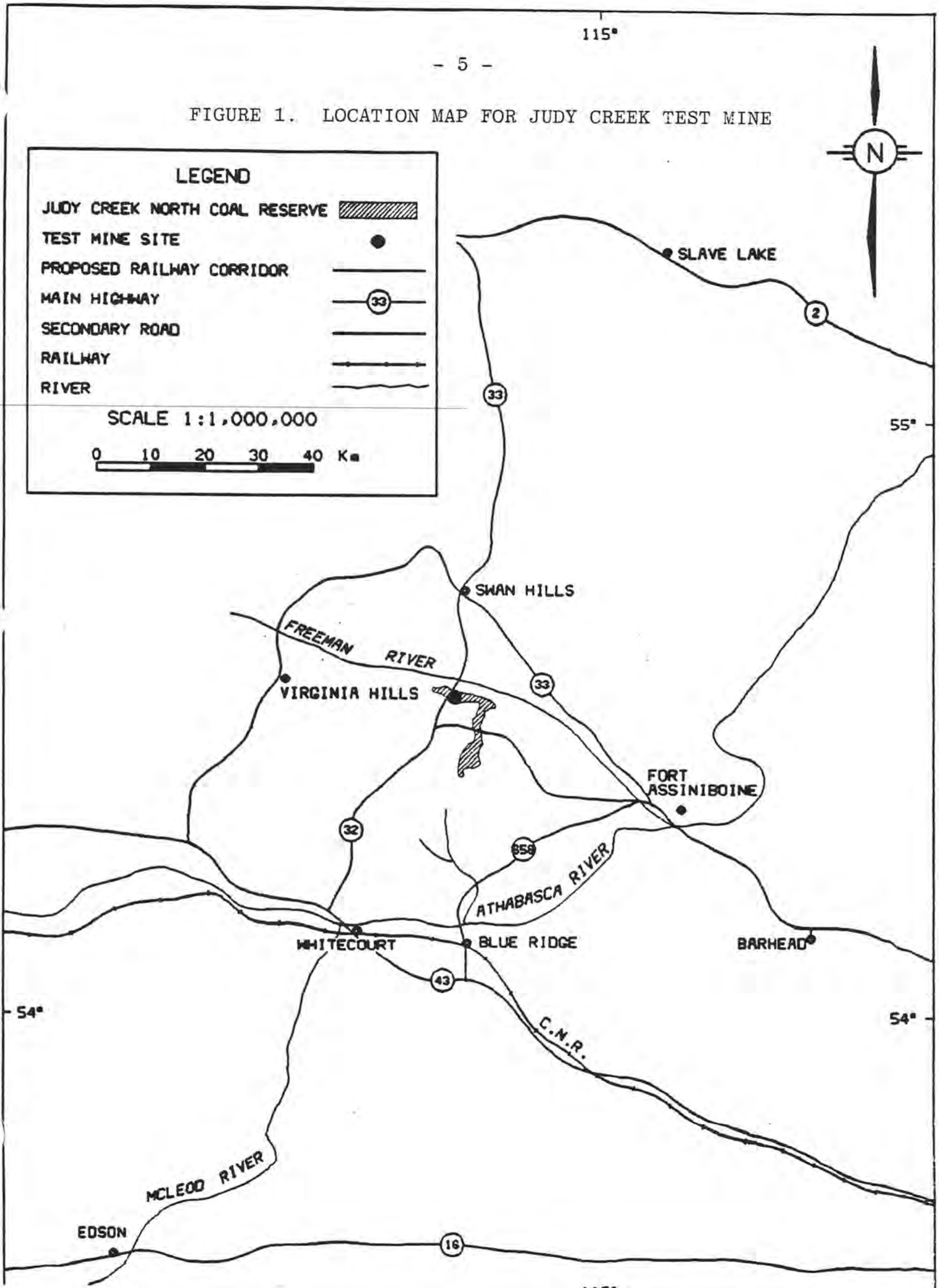
During the winter of 1978 Esso Resources Canada Ltd. constructed a test mine on the Judy Creek North Coal Reserve. The test mine was designed to secure a 10,000 tonne bulk coal sample for a test burn (Esso Minerals Canada, 1979). Constructon and subsequent reclamation procedures provided a site suitable to examine effects of various soil depth replacements on reclamation success. The present paper describes the soil depth study methodology and discusses the results of five years of study.

STUDY AREA

The Judy Creek Test Mine is located within the Judy Creek North Coal Reserve approximately 56 kilometers (km) south of Swan Hills, Alberta and 2 km east of Highway 32. The test mine is located in the NW 1/4, Section 14, Township 64, Range 10, west of the 5th meridian (Figure 1).

An area of 17.3 hectares (ha) was cleared for test mine operations in December, 1978; of which the test pit itself comprised 1.5 ha. An additional 2 ha area (2 km in length) was cleared as an access road to highway 32.

FIGURE 1. LOCATION MAP FOR JUDY CREEK TEST MINE



The test mine area is regionally characterized by warm summers and cold winters. Mean daily temperatures vary from a low of -17 degrees C (in January) to a high of 20 degrees C (in July). Average annual total precipitation is about 53 centimeters (cm) of which approximately 33% is received as snowfall. The prevailing wind directions are west and northwest.

The test mine lies at the western edge of the western plains physiogeographic region, in what is termed the Rocky Mountain Foothills area of Alberta. Elevations in the area range from 600 m on the Freeman River to over 1400 m in the Swan Hills. The hydrography of the area is dominated by the Freeman River, the Judy Creek, and the Christmas Creek; all tributaries of the Athabasca River.

Forest cover in the test mine area is dominated by stands of white spruce (*Picea glauca*) and the lodgepole pine. Pine and spruce occur as a mosaic of even-aged pure stands, depending on slope, or as stands of various mixtures of pine and spruce mixed-wood forests of either pine or spruce and aspen (*Populus tremuloides*) or balsam poplar (*Populus balsamifera*). Shrublands occur as clumps of mainly willow (*Salix sp.*) along the riparian sites or, to a minor extent on roadways and access clearings.

METHODS

The soil depth study consisted of nine 20 m X 40 m plots numbered 1.1 through 1.9 (Figure 2). Different depths of surface soil were placed over till overburden in spring 1979. Surface soil included all material in the A and B horizons and was collected in two lifts and stockpiled prior to placement on study plots in 1979. Analysis of the till overburden indicated no parameters limiting growth (Table 1; Esso Minerals Canada, 1979). Study plots 1.1, 1.2 and 1.3 received 70 cm (27.5 inches) of surface soil; plots 1.7, 1.8, and 1.9 were topsoiled with 30 cm (11.8 inches) of surface soil; the remaining plots (1.4, 1.5 and 1.6) had no surface soil replacement.

Each plot was planted with a complete grass/legume seed mixture by hand broadcast seeding. A description of the seed mix and broadcast rate is given in Table 2. Based on previous soil sampling (Esso Minerals Canada, 1979), fertilizer (23-N, 23-P, 0-K) was applied to each plot at a rate of 160 Kg/ha. No further ammendments or fertilizers have been applied. In addition to the application of an agronomic seed mixture ninety-eight lodge-pole pine seedlings were planted within each of the study plots. Twenty-four of these trees were randomly selected as study trees and permanently marked with wooden stakes equipped with metal identification tags. Planting occurred on June 1 and 2, 1979 using both V-bar and shovel mattock techniques. All trees were one-year old at planting and were spaced at 2.4 to 2.7 intervals within each plot.

Revegetation success for each soil depth treatment was evaluated through the measurement of plant cover. During August of 1979, and June and August of 1980, 1981 and 1983 vegetation cover estimates were made in each plot. Vegetation cover in each plot was determined through the observation of the proportion of ground covered by seeded revegetation species in forty evenly spaced 20 cm by 50 cm quadrats. Cover within each quadrat was estimated using the Braun Blauquet method (Kershaw 1973).

FIGURE 2. PLOT PLAN FOR SOIL DEPTH STUDY

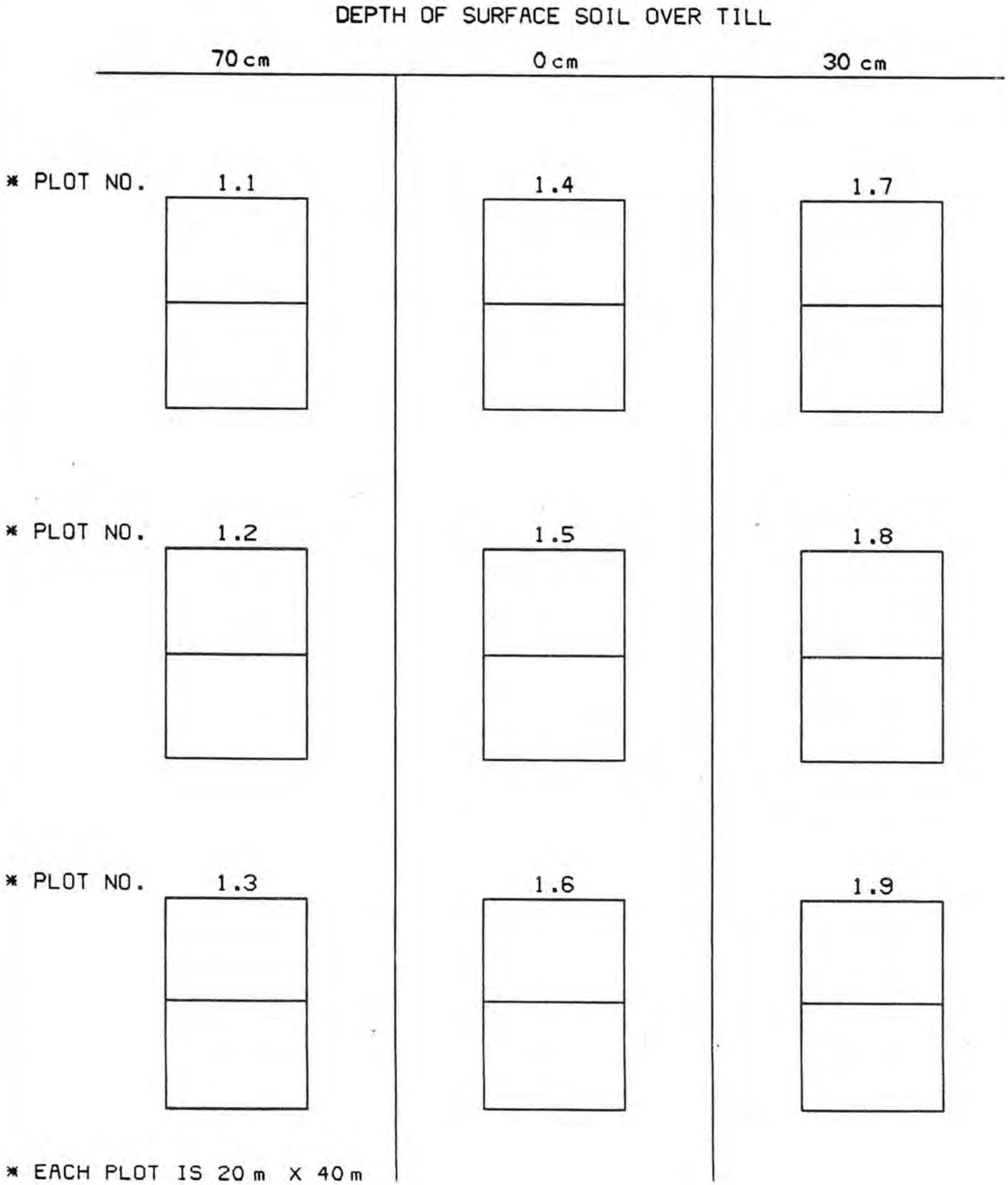


Table 1. Chemical Analysis Of Till Overburden Material

PARAMETER	Sample Number				
	1	2	3	4	Average Value
pH (aqueous)	6.7	6.4	8.0	7.5	7.15
pH ($CaCl_2$)	6.2	6.4	7.2	7.4	6.80
S.A.R.	0	0.08	0	0	0.02
Exchangeable Cations (Meq/100g)					
NA	0.15	0.25	0.25	0.30	0.24
K	0.55	0.55	0.30	0.60	0.50
CA	17.50	21.20	14.1	13.20	16.50
Mg	5.90	5.50	2.7	5.80	4.90
C.E.C.	23.20	27.70	13.4	27.70	23.00
Available P (ug/g)	7.50	19.00	-*	12.00	12.80
Available N (ug/g)	0.80	2.55	0.85	0.45	1.16
Available K (ug/g)	260.00	260.00	140.00	285.00	236.30
Organic Matter (%)	1.4	2.2	0.90	2.00	1.60
$CaCO_3$ Equivalent (%)	-	-	21.90	25.70	23.80

* Dash indicates data not available.

Table 2. Description Of Seed Mixture Applied To Soil Depth Treatment Plots

Species	Variety	Percent of Mix (by wt.)	Broadcast Seeding (kg/ha)	Features and Tolerances
Grasses				
Canada bluegrass (*Poa compressa*)	Common	20	6.0	Low maintenance, tolerance to grazing, aggressive, drought tolerant
Creeping red fescue (*Festuca rubra*)	Boreal	15	4.5	Tolerant to grazing, good seedling vigor, sod forming
Slender wheatgrass (*Agropyron trachycaulum*)	Revenue	10	3.0	Strong root system for erosion control
Crested wheatgrass (*Agropyron (cristatum)*)	Fairway	15	4.5	Good seedling vigor, can withstand traffic
Timothy (*Phleum pratense*)	Climax	10	3.0	Rapid establishment, fibrous roots
Smooth brome (*Bromas inermis*)	Carlton	10	3.0	Long-lived, sod forming
Legumes				
Alfalfa (*Medicago sativa*)	Drylander	10	3.0	Superior winter hardiness, drought resistant
Red clover (*Trifolium pratense*)	Altaswede	10	3.0	Short-lived, winter hardy, acid tolerant
		100	30.0	

Reforestation success for each soil depth treatment was determined through evaluation of the survival and growth of each permanently marked tree. Estimation of tree survival and growth was conducted during August, 1979 and June and August of 1980, 1981 and 1983. Only tree survival was evaluated during June, 1982. Tree survival was determined through evaluation of the survival status of each marked tree (ie. living or dead). As a method of data reduction a mean total survival value was calculated for each treatment based on the equation; TL/TM x 100; where TL equals total living marked trees per plot, and TM equals the total marked trees per plot. Growth was recorded by measuring the height of each marked tree with a graduated meter stick. Height is considered a true indicator of growth, and therefore basal diameter was not measured. Incremental growth was determined through measurement of the new vertical leader growth for each year.

Soil samples were taken from each study plot in 1979, 1980, 1981 and 1983. Four subsamples were taken at randomly spaced locations within each study plot and combined by treatment for analysis. Samples were taken from the 0 to 15 cm soil layer. Analysis of soil samples followed procedures reported in McKeague (1978). During 1979, 1980 and 1981 the level of available macronutrients including Nitrogen (NO_3-N), phosphorous (P), potassium (K), and sulphur (SO_4-S), pH, electrical conductivity, and percentage organic matter, were recorded for each treatment. During 1983 the pH, conductivity, available macronutrients, calcium carbonate equivalent, extractable and soluble cations, cation exchange capacity, percentage saturation, sodium absorption ratio, particle size distribution, moisture content (percentage) and bulk density were determined for each treatment.

Statistical analyses were conducted using the SAS Proc Anova Statistical test (SAS 1982).

RESULTS

SOIL CONDITIONS

The chemical and physical parameters of the soils for each soil depth treatment by year are given in Table 3. Soil pH during the study ranged from 5.3 to 7.5 with the 30 cm and 70 cm plots consistently having lower values. Values of calcium carbonate equivalence recorded in 1983 indicated that all treatments have no capability problem with respect to alkalinity but the 0 cm plots were more alkaline than the 30 cm or 70 cm plots. All study plots had sodium absorption ratio values (in 1983) corresponding to a 'good' soil capability rating (Alberta Agriculture 1981a) indicating no sodicity problems.

Levels of all macronutrients (NO_3-N, P, K) on each treatment were well above those reported values required to support graminoid growth (Williamson et al., 1982). Very little between plot variability was recorded and nutrient availability was consistent within any one treatment.

The organic matter content was found to be consistently higher (for years 1979-1981) for the 70 cm study plots than the 30 cm and 0 cm plots. An inverse relationship between bulk density on the 70 cm and 30 cm plots was observed. The cation exchange capacity (CEC) in each study treatment was very similar, possibly due to the higher clay component of the 0 cm plots which would offset the cation exchange ability of the organic material in the 70 cm and 30 cm plots. All CEC values recorded were well above those recorded for typical natural forest soil types of similar chemical and physical make-up (Williamson et al., 1982).

Based on the particle size distribution conducted in 1983 the surface soil on the study plots can be characterized as follows. The 70 cm and 0 cm treatments are considered a clay loam and the 30 cm treatment a loam.

REVEGETATION

Percentage cover data for grasses, legumes and total living cover are shown in Figure 3. Cover increased dramatically from 1979 to 1980 on all plots and tended to level off from 1981 to 1983. Legume cover was consistently higher than graminoid cover throughout the study period.

The 0 cm soil depth treatment provided highest cover estimates in terms of total living cover for each year of study. This difference was statisticaly significant ($F = 3.44$, probability less than or equal to 0.05). Graminoid cover was also more apparent on the 0 cm plots for all years with the exception of 1983. Cover values for graminoids were statistically different for each treatment ($F = 3.67$, probability less than 0.05). Legume cover was also recorded at higher levels on the 0 cm plots than the 30 and 70 cm treatments ($F = 6.16$, probability less than or equal to 0.05).

able 3. Results of Soil Sampling Analyses for Soil Depth Study, 1979-1983

epth of oil cm)	Year	pH	Conduct-ivity (mmhos/cm)	Organic Matter %	NO_3-N (ppm)	P (ppm)	K (ppm)	SO_4-S (ppm)	Bulk Density (g/cc)	Moisture Content %	$CaCo_3$ Equiv. %	CEC (Meq/100g)	Satura-tion %	SAR	Particle Size (%) Sand	Silt	Clay
	1979*																
'0		6.0	0.1	3.1	1.7	9.0	126.7	3.0	***								
30		6.4	0.2	1.7	2.0	8.3	93.3	4.0									
0		7.5	0.4	1.7	2.0	5.3	123.3	9.0									
	1980*																
70		5.5	0.2	2.5	1.0	11.0	162.0	2.0	1.2	32.8							
30		5.9	0.3	2.0	1.0	11.0	160.0	7.0	1.3	26.3							
0		7.4	0.6	1.4	1.0	9.0	188.0	8.0	1.5	23.7							
	1981*																
70		5.3	0.1	2.9	2.0	10.0	152.0	3.0									
30		5.8	0.2	1.6	2.0	10.0	137.0	3.0									
0		7.3	0.5	1.4	3.0	7.0	173.0	9.0									
	1983**																
70		7.1	0.2		0.9	8.0	135.0	5.0	1.2	32.9	0.21	24.1	46	1.2	29.1	40.9	29.9
30		5.5	0.3		0.9	7.0	110.0	12.5	1.2	27.1	0.12	20.2	38	0.5	36.9	37.1	25.9
0		7.0	0.4		1.4	3.5	140.0	14.0	1.4	23.8	1.94	22.8	50	0.4	33.6	32.2	34.2

* Measurements based on mean values for three plots
** Measurements based on composite sample for 3 plots per treatm[illegible]t
*** Blank inc[illegible]tes measurement not available

Cover estimates for each planted species by soil depth treatment are given in Table 4. Timothy and Creeping red fescue were consistantly the most abundant seeded graminoid species on all of the soil depth plots. Other seeded species such as Canada blue grass and Crested wheatgrass were recorded at low cover values, and other species such as Slender wheatgrass and Smooth brome were recorded at only marginal abundances. Red clover had consistently high cover estimates on all treatments during each year of study. Alfalfa, the only other seeded legume, was recorded at low cover on all treatments with the exception of the 0 cm treatment. The increased cover of Alfalfa on these plots is due to the more alkaline soil conditions making the 0 cm plots more condusive to Alfalfa growth (Alberta Agriculture, 1981b)

REFORESTATION

Data on the mean percentage survival of lodgepole pine outplanted in 1979 for soil depth treatments are shown in Figure 4. The 0 cm soil depth treatment consistently showed lower mean survival than the 70 cm or 30 cm soil depth treatments. Further, the difference in survival became more pronounced in subsequent years of study. Differences in total mean percent survival between the 70 cm and 30 cm soil depth treatments were negligible for all years of study.

The total yearly growth and total incremental growth as indicated by height measurements, is shown in Figure 5 and Figure 6 respectively. Growth, in terms of total height was significantly reduced on the 0 cm treatment from

FIGURE 3. PERCENTAGE COVER OF GRASSES, LEGUMES AND TOTAL LIVING COVER FOR SOIL DEPTH TREATMENTS

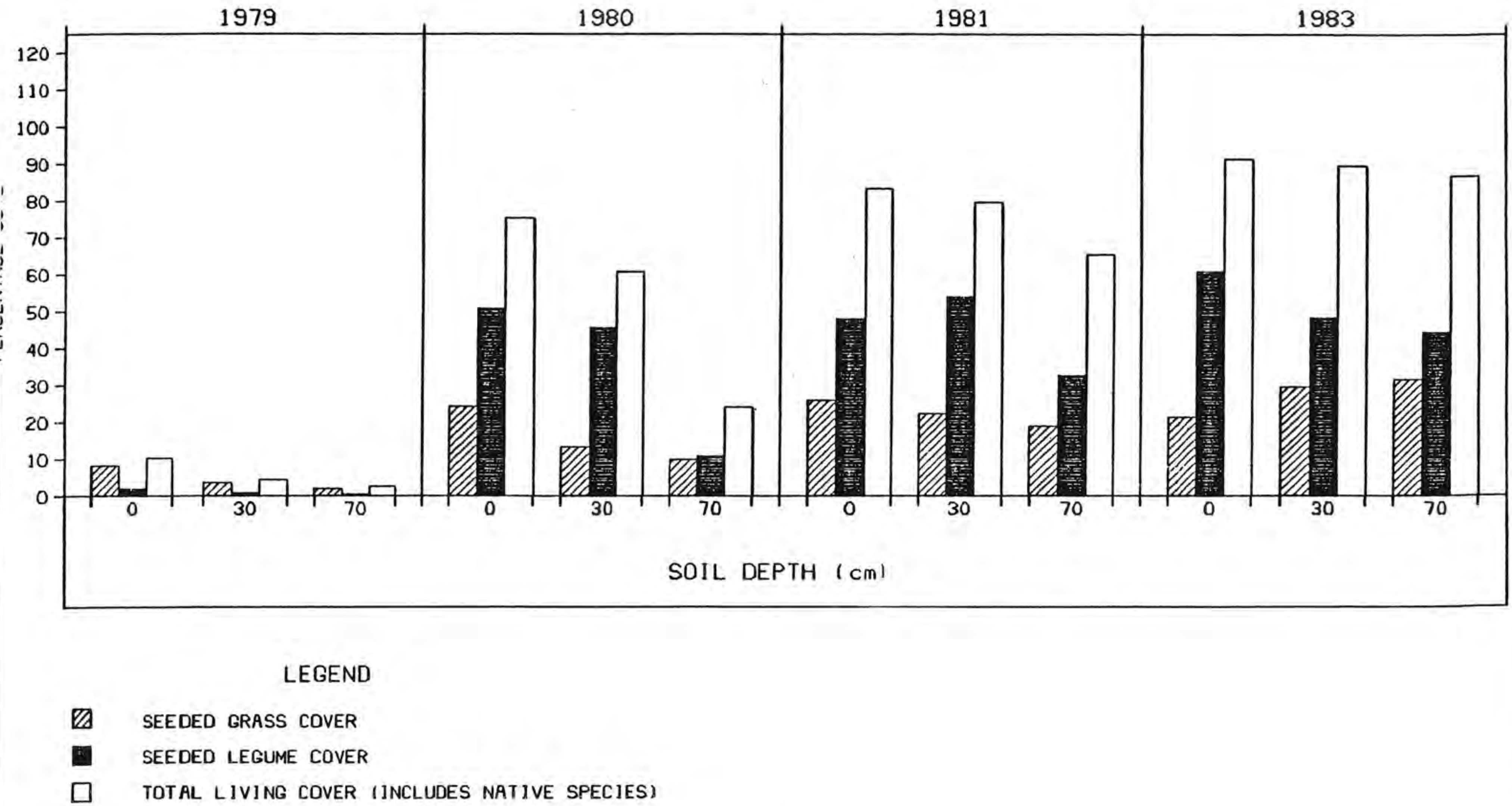


Table 4 Average Percentage Cover Values By Species Recorded For Soil Depth Treatments

Seeded Species	MEAN PERCENTAGE COVER *								
	70 cm TREATMENT			30 cm TREATMENT			OCM TREATMENT		
	1980	1981	1983	1980	1981	1983	1980	1981	1983
Canada Bluegrass	0.80	1.56	3.35	0.37	1.70	3.08	0.63	1.70	2.08
Crested Wheatgrass	0.13	0.10	0.00	0.20	0.23	0.10	1.60	0.60	0.19
Slender Wheatgrass	0.43	0.43	0.48	0.57	1.13	2.49	3.26	2.10	1.26
Smooth Brome	0.40	0.00	0.11	0.00	0.00	1.00	0.80	0.00	2.23
Creeping Red Fescue	3.77	7.83	21.37	6.97	9.67	15.16	7.90	9.80	11.69
Timothy	4.66	9.03	6.12	5.23	10.23	7.72	10.03	12.16	3.69
Red Clover	10.83	32.13	43.83	52.30	53.90	48.25	44.80	35.47	26.53
Alfalfa	0.10	0.10	0.34	0.10	0.00	0.00	6.03	12.67	34.08

* Based on average of 120 quadrats per treatment for each year.

that observed on the 70 and 30 cm treatments (F = 7.15, probability less than or equal to 0.05). Pine growth was similar between the 70 cm and 30 cm treatments (F = 1.34, probability greater than or equal to 0.05).

DISCUSSION

Previous research by Pole et al. (1979); Sandoval and Gould (1978); Huntington et al. (1980) has shown that soil depth replacement over mine spoil can affect revegetation success. Power et al. (1976) further report that yield (tons/ha) of spring wheat will increase with depth of topsoil up to about 71 cm, with greater thicknesses resulting in no further yield increases. Power et al (1981) reported that vegetal yield increases with soil depth to a maximum of approximately 90 cm. Additional soil replacement does not appear to provide increases in yield. Logan (1983) concurred with the results of Power et al (1981) and stated that reduced soil thickness may relate to a reduced productivity but not to no productivity at all.

Data from the Judy Creek study indicate that soil depth replacement on suitable till subsoil does not have a pronounced effect on revegetation success. In the present study reduced soil depth replacement over till did not appear to limit vegetal growth as has been observed in other sodic spoil soil replacement studies.

FIGURE 4. SURVIVAL OF LODGEPOLE PINE BY SOIL DEPTH TREATMENT

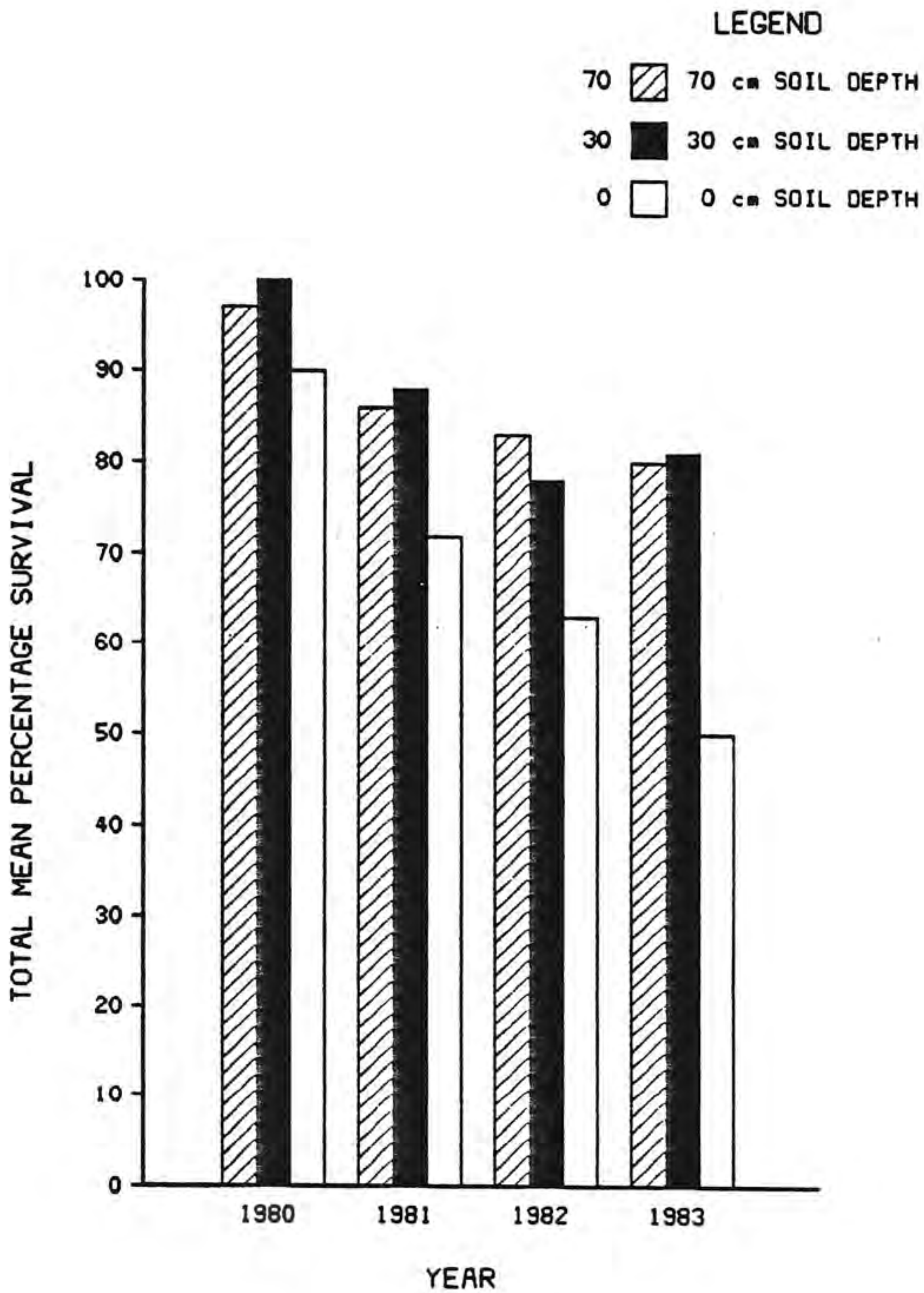


FIGURE 5. LODGEPOLE PINE HEIGHT MEASUREMENTS FOR SOIL DEPTH STUDY

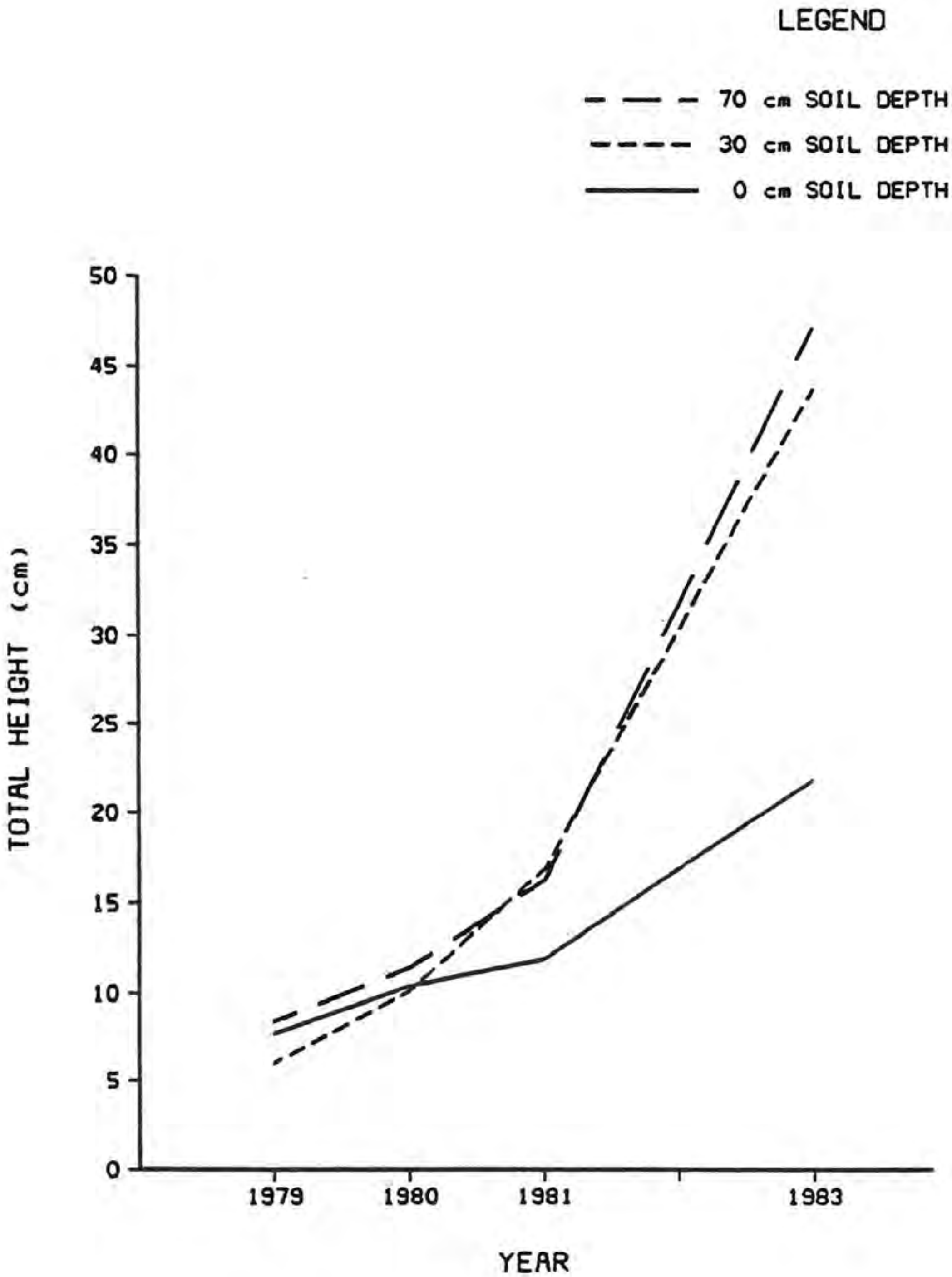
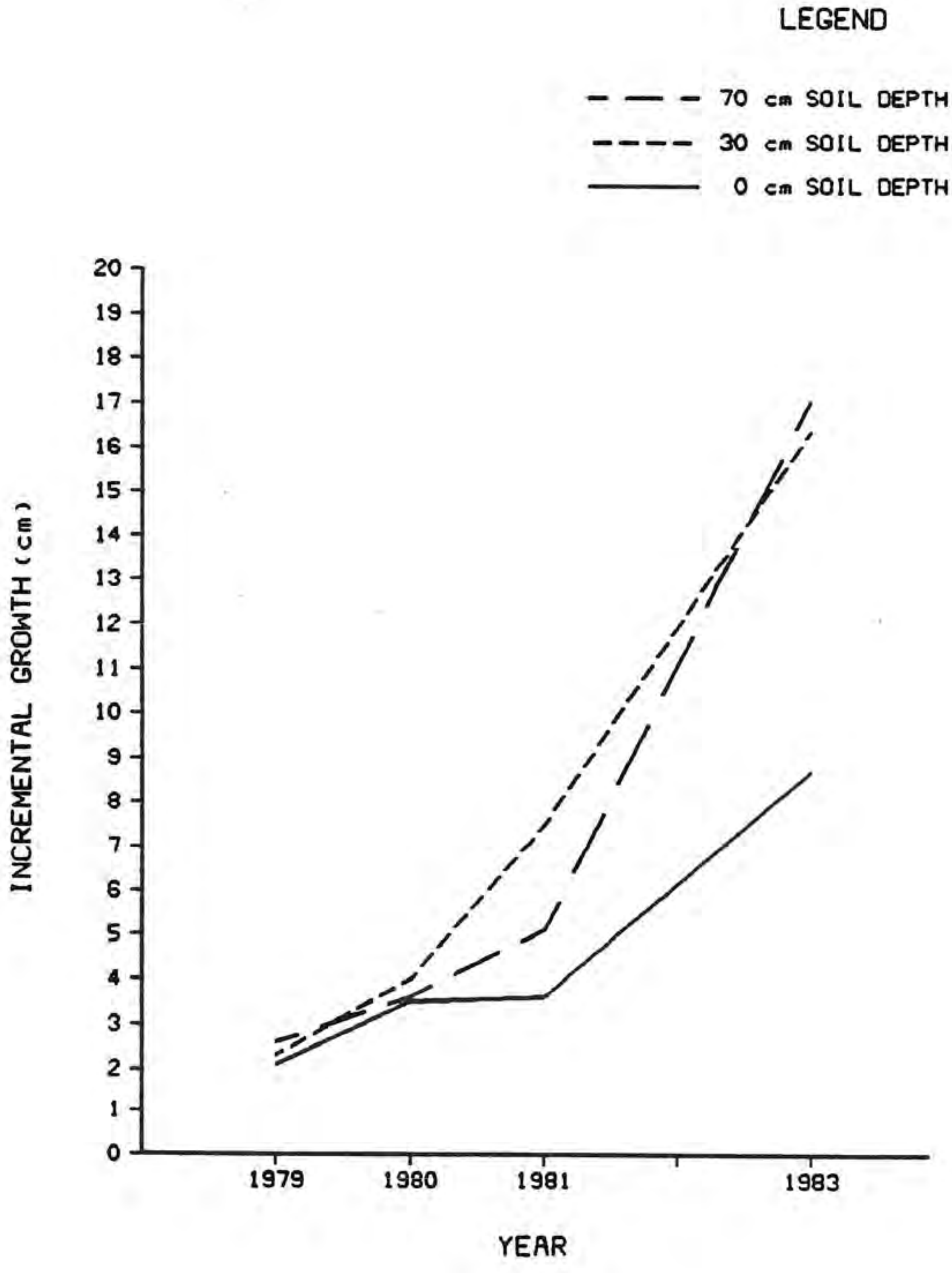


FIGURE 6. LODGEPOLE PINE INCREMENTAL HEIGHT MOVEMENTS FOR SOIL DEPTH STUDY



Research on the topic of appropriate soil depth replacement for reforestation has not been forthcoming. However, Krumlik (1980), in a study designed to examine soil and tree rooting depth relationships in Alberta, reported that the relationship between soil depth and tree growth appears to be poorly correlated. Other soil parameters such as pH, moisture, texture and temperature appear to more strongly influence tree growth. Further, tree growth on reclamation sites has been shown to be influenced by competiton from herbaceous vegetation and by small mammal damage (Green, 1982).

Results from the Judy Creek study concur with these previous studies. Reduced lodgepole pine servival and growth on the 0 cm soil depth treatment is most likely due to the combined effects of lower soil moisture, lower pH, compaction of the till material and competition by dense herbaceous cover. Further, the more dense herbaceous cover on the 0 cm plot increased the potential for small rodent caused pine seedling mortality (Esso Resouces Canada Ltd., 1984).

CONCLUSIONS

Results from this study have implications related to materials handling in reclamation programs in boreal regions of Alberta. Addition of forest soils as "topsoil" over suitable till subsoil may not be required to provide improved revegetation cover. However, on sites where little or no "topsoil" is added, monitoring of reforestation success is recommended.

ACKNOWLEDGEMENTS

MESSRS. D. James, H. Martens, and C. Warner; Hardy and Associates (1978) LTD. assisted with the field work and initial data reporting for this study. G. Mann provided editorial assistance. This study was supported through funds supplied by Esso Resources Canada Ltd. and Trans-Alta Utilities Corporation.

LITERATURE CITED

Alberta Agriculture. 1981a. Proposed Soil Quality Criteria In Relation To Disturbance and Reclamation. Report prepared by the Soil Quality Criteria Subcommitte for Alberta Soil Advisory Committe. Alberta Agriculture 53 pp.

Alberta Agriculture, 1981b. Alberta Forage manual. Report Agdex 120/20-4. 87 pp.

Colorado School of Mines. 1983. Soil Depth Requirements To Reclaim Surface Mined Areas In The Northern Great Plains. Report prepared for U.S.D.I., The Bureau of Mines. 343 pp.

Doering, E. J. and W. O. Willis. 1975. Chemical Reclamation For Sodic Strip-mined Spoils. U.S.D.A. publication ARS-NS-20. 8 pp.

Esso Minerals Canada. 1979. Final Reclamation Plan; Judy Creek Test Pit. Unpublished report submitted to Alberta Energy and Natural Resources. 85 pp.

Esso Resources Canada LTD. 1984. Judy Creek Test Mine Reclamation Studies. Unpublished report submitted to Alberta Energy and Natural Resources. 360 pp.

Green, J. E. 1982. Small Rodent Populations And Related Damage To Trees And Shrubs On Reclamation Areas. Unpublished report prepared for Alsands Energy LTD. and Suncor Inc. by L.G.L. LTD. 121 pp.

Huntington, T.G., R.I. Barnhisel, and J.L. Powell. 1980. The Role Of Soil Thickness, Subsoiling And Lime Incorporation Methods On The Reclamation of Acid Surface Mine Spoils. Pages 9-13 IN: Symposium on surface mining hydrology, sedimentology and reclamation. Lexington Kentucky. December 1-5, 1980.

Kershaw, K.A. 1973. Quantitative And Dynamic Plant Ecology. Edward Arnold Publishers, London. 306 pp.

Krumlik, G.J. 1980. Soil And Rooting Depth Patterns In North-East Alberta. Pages 49-60 IN: Ziem Kiewicz, P.F. Takyi, S.K., Regier, H. (Eds) Proceedings: Workshop On Reconstruction Of Forest Soils In Reclamation. Alberta Energy and Natural Resources RRTAC Report #80-4.

Logan, R.J. 1983. Soil Handling Aspects Of Coal Mine Reclamation On Agricultural Lands. Pages 82-86 In: Proceedings: 2nd Alta. Reclaim. Conf.. C.L.R.A. Alta. Chapter Report #CLRA/AC 83-1.

McKeague, J.A. 1978. Manual Of Soil Sampling And Methods Of Analysis. Canadian Soil Survey Committee Report. Can. Society of Soil Science. 167 pp.

Pole, N.W., A. Bauxer, L. Zimmerman, and S.W. Melsted. 1979. Effects Of Topsoil Thickness Placed On Spoilbanks On Wheat and Corn Yields In North DaKota. Pages 64-71 In: CLRA 4th Annual Meeting, July 13-15, Regina, Sask.

Power, J.F., F.M. Sandoval, R.E. Ries, and S.D. Merril. 1981. Effects Of Topsoil And Subsoil Thickness On Soil Water Content And Crop Production On A Distributed Soil. Soil Science Society of America Journal 45: 124-129.

Power, J.F., R.E. Ries, and E.M. Sandoval. 1976. Use Of Soil Materials On Spoil: Effects Of Thickness And Quality. North Dakota Farm Research 34(1):23-24.

Sandoval, F.M. and W.L. Gould. 1978. Improvements Of Saline And Sodium Affected Disturbed Lands. Pages 495-504. In: Reclamation of Drastically Disturbed Lands. Schamller F.W. and P. Sutlon (Eds). Amer. Soc. of Agronomy.

SAS. 1982. SAS Users guide: Statistics. Statistical Institute, Statistical Analyses System, Cary, North Carolina. 494 pp.

Williamson, N.A., M.S. Johson, and A.D. Bradshaw, 1982. Mine Wastes Reclamation. Mining Journal Books LTD. 97 pp.

PREPARATION OF MINE SPOILS FOR TREE COLONIZATION OR PLANTING

D.F. FOURT
UNITED KINGDOM, FORESTRY COMMISSION

An inevitable consequence of most mining operations is the disturbance and removal of soil horizons developed over the mineral deposit or its over-burden.

If previous site investigations have indicated the presence of physical or chemical factors likely to cause problems when re-assembling the components of the future soil, measures should then be taken to quantify them, and decide on their disposal or amelioration, or the sequence required to minimize their influence.

This is the time to examine the geological column or borehole log, and decide which strata are better replaced low down, and which could improve the soil, if used to correct defects of texture, or porosity, especially in the subsoil.

When the future land use is to be planted or naturally regenerated woodland, it can be useful to put together a prescription containing certain criteria essential for that purpose. Compared with grass swards, woodlands, especially newly planted trees, need a much greater rooting volume, with a larger moisture store, related to summer soil water deficits calculated from Penman-Monteith type evapotranspiration equations. To store arount 15-20 cm of rainfall equivalent requires at least 75 cm depth of porous rootable soil, and this large volume is usually able to supply the needs of the young trees for the mineral nutrients P, K, Ca and Mg. The demands for nitrogen are much lower than are required for grasses and herbs, and can usually be satisfied from the replaced topsoil. Nitrogen deficiency reduces growth, but rarely proves fatal - this is usually due to moisture stress.

It is our experience that soil analysis by assay with various extracting solutions designed to simulate root activity, has little to offer the forester in deciding on nutrient element requirements and amendments. They have found that analyses of foliage taken from about the third season, onwards, at a standard time, and position, best enables any requirements to be decided. These criteria have been reviewed by I.K. Morison of the Canadian Forest Service in a useful publication entitled "Mineral Nutrition of Conifers" (1974 ref.).

We have also used pot trials to assess the nutrients in overburden, or other spoils, by using a convenient leguminous herb - in our case a lupin - which is grown from seed for 15 weeks in a coffee-cup sized container of media, with a P, K factorial, and suitable replication. In addition to the comparisons of height, or oven-dry weight, the tissue can be analyzed and compared with standards. The use of nodulated legume avoids the complication of nitrogen as a limiting factor, enabling the researcher to concentrate on those nutrients contained in the mineral part of the new soil.

Once the available reserve of water has been assured, the supply of nitrogen is likely to be the next factor limiting growth. If present in even modest amount, the fine root system of sown or native grasses will mop it up and reduce or threaten the growth of the young trees, and in the process dry out the surface layers. Some relief from moisture stress by local grass control (Sale et al. 1983) or mulching is usually beneficial, but can be expensive and interfere with erosion control measures.

In the absence of conserved topsoils and their store of nitrogen held in the organic fraction, the components of the pioneer tree cover should simulate the natural sequence on the tail of a glacier and consist of, or be in matrix with, nitrogen fixing tree species or herbs such as alders or legumes. The forest is characteristically designed to accumulate and conserve nitrogen, as litter or live tissue, and even the small amounts in rainfall, or brought into cycle from ground water are likely to be accumulated over the life of the trees, rather than lost by leaching or grazing, once the tree canopy is closed.

However, many reclamation practitioners have learnt from field experience, that some fossil nitrogen in the form of amino-acids, is present and sparingly available in a range of dark coloured sedimentary rocks such as occur as coal overburden (Aldag et al. 1980) boulder till, or in carbonaceous silts or shales or in brick clays. In northern climates, or in high rainfall areas, peat covers may also be present, and their valuable nitrogen store should be conserved for subsequent use during revegetation (Fourt 1984).

Fertilizer nitrogen is sometimes considered, and specified in factorial experiments designed to compare the benefits to tree growth of matrices of Frankia inoculated alders, Rhizobium inoculated legumes or organic mulches. The results vary, but low retention, insufficient uptake, and expense, all count against their use in forestry - a very low intensity land use where cash returns are typically long-delayed.

It is sometimes argued that the nitrogen is best retained in the cycle by grasses and herbs before the tree canopy shades them out. But adding nitrogen increases their competitive ability and operates against easy establishment and growth of the trees.

As previously mentioned, the provision of a substantial volume (0.75 - 1.0 m thick) of easily rootable aerated mineral spoil is the best way to get newly planted trees established. Shallower root zones, limited by compaction, or texture class reduce growth by restricting stomatal opening and, through this, photosynthesis. The cause of this growth reduction can be misleading. Grasses on thin root-zones may respond to added nitrogen, but at the cost of superficial root habit. Trees do not obtain long-term benefit, because the limiting factor is water (Binns and Crowther 1983).

A brief history of open pit mining records the early days of the big machines with the jagged spoil heaps from dragline overburden removal called "Hill and Dale". Several other excavators also produce such patterns, such as face shovels, and hydraulic buckets. Although alien to the landscape these loose heaps grow good trees - often as good as the forests present previously. All efforts at grading these heaps resulted in poorer growth, due to compaction, waterlogging or drought due to constriction of rooting volumes.

The recognition that some form of loosening was required following dozer-grading of hill and dale, or box-scraper laid overburden or topsoil, resulted in a range of ripping, ploughing or other treatments designed to open or replace the coarse pores squeezed out by the machine passes. In the UK we have a range of equipment, especially winged tine sets, attached to or trailed behind the Caterpillar D8 class of prime mover (Binns and Fourt 1981).

Sites intended for forestry are easy to plant following treatment with 3 winged tine sets, but on heavier clay-loam to clay spoils, an additional treatment with angled discs elevates the planting position on a small ridge, enhancing early growth and establishment.

Our agriculatural colleagues use multi-tine sets, with plain tines ahead of winged tines followed by heavy disc sets to break clods before seedbed preparation.

Most practitioners now recognize the importance of season, and soil conditions in earth moving, and we now insist or persuade operators to do so only during the reclamationn "window" from May or early June, to late August or early September (Binns 1983) when conditions are dry.

Ground preparation treatments for forestry generally require the provision of gradients for drainage, as either ridge and furrow below 5°, or open contour ditches above 5°. In agriculture backfilled pipe drains followed by annual secondary treatments with moles or cultivators are possible, but the forester does not have this option once the trees are planted, making it essential that the physical constraints are ameliorated first time, and when the machines are available. During the last few years, a noticeable shift in technology seems to have provided another system for the forester, and possibly for the agriculturist carrying out reclamation. On many sites, electric or diesel hydraulic bucket excavators of all sizes are backed up by a wide range of dump trucks, for overburden removal. Sizes range from frame-steered 6 x 4 or 6 x 6 vehicles from 10 - 30 cu.m., to the giant 50, 75 and 100+ sizes.

Instead of the liner heaps of the dragline, loose tipped spoil can be laid to a pattern of overlapping hummocks to produce 1.0 3.0 m layers of mineral debris, each butting onto those placed before and giving a micro-topography rather like the natural forests with their relics of windthrown or fallen trees. These minor declivities trap seeds, litter, snow, etc. and provide a range of micro-habitats for seeding germination of varied aspect and shelter. The material does not need any ripping - in fact great effort should be made to keep machines off the surface at all costs, especially those dozer drivers with a passion for back-blading.

For forestry, less segregation of topsoil, felling debris, and leaf-litter is necessary compared with sites intended as grassland or other agricultural uses. These valuable organic materials can be mixed with the loose spoil provided aeration and drainage are good, and mineralization will be aerobic.

This system has been used in agriculture on market-garden soils, the loose tipped surface being graded using a side-acting bucket on a long-jib excavator working from the adjacent quarry floor. The same bucket can be used to spread topsoil, where conserved separately, all without machine traverse of the surface (Bransden 1980).

The system is cheap, where no grading or ripping is needed. What it does need is some training of dumper drivers, but we find that they soon get the idea, and take pride in forming the required pattern. As in all reclamation, unless the machine drivers are enlisted into the process, each with their own instructions, and contact with the end-user, they will fail to distinguish between unnecessary elaboration or interference with established practice and their own interest - where good reclamation and return to beneficial land use have influence on new mining permissions.

To sum up, for good tree establishment, large volumes of loose mining material are required to provide moisture storage over the summer deficit period, and to supply adequate amounts of the mineral nutrients P, K, Ca and Mg, without amendment.

Nitrogen, the most vulnerable plant nutrient element in reclamation operations, needs either organic matter conservation and replacement, N-fixing plant or tree matrices, or may be present in fossil forms in carbonaceous shales and sandstones. Fertilizers are expensive, poorly utilized and can accentuate competition especially with sown swards intended for erosion control.

Although the loose spoil from dragline stripping affords good rooting conditions, hill and dale is environmentally unacceptable. Unfortunately grading operations produce compaction, needing alleviation by deep-ripping. Instead, patterns of loose-tipping from dump trucks are suggested where trees are to be grown. The large rootable volume, and the range of micro-climates which trap seeds, litter and snow, are cheap to form, need no further treatment, once the work force appreciates their purpose.

REFERENCES

Alldag, R.W. and Z. Strzyscz. 1980. Inorganic and Organic Nitrogen compounds in Carbonaceous phyllosilicates on spoils with regard to Forest Reclamation. Reclamation Review 3(2)69-73.

Binns, W.O. and D.F. Fourt. 1981. Surface working and trees in "The productivity of restored land" p. 23-29. publ. Land Decade Educational Council London.

Binns, W.O. 1983. Reclamation of Mineral Workings to Forestry. For. Comm. London. R & D paper 132.

Binns, W.O. and R.E. Crowther. 1983. Land reclamation for trees and woods. Reclamation 93. p 23-28. Industrial Seminars Ltd. London.

Bransden, B. 1980. Pers. Comm.

Fourt, D.F. 1981. The afforestation of open cast mining spoils in the United Kingdom - some techniques and observations. "Reclamation in Mountainous Areas". Proceedings 6th Ann. Meeting CLRA.

Fourt, D.F. 1984. Site Studies (S). For. Comm. Ann. Rep 1983.

Haldin, S. 1979. Comparisons of forest water and energy balance models. I.U.F.R.O. Workshop. Elsevier.

Monteith, J.L. 1965. Evaporation and environment pp. 205-234. Symp. Soc. Expl. Biol. 19.

Morrison, I.K. 1973. "Mineral Nutrition of Conifers". Forest Service Publication 1343. Environment Canada.

Sale, J.S.P., P.M. Tabbush and P.B. Lane. 1983. The use of herbicides in the Forest. For. Comm. London. Booklet 51.

WATER BALANCE SHEET

MONTH (1)	RAINFALL (2) mm	EVAPORATION + (3) mm	DIFFERENCE (4) mm	DEFICIT (5) mm	RAINFALL (−30%)* (6) mm	DIFFERENCE (7) mm	DEFICIT (8) mm
APRIL	43	49	−6	−6	30	−19	−19
MAY	49	77	−28	−34	34	−43	−62
JUNE	55	92	−37	−71	38	−54	−116
JULY	52	95	−43	−114	36	−59	−175
AUGUST	61	80	−19	$\boxed{-133}$	43	−37	−212
SEPTEMBER	49	42	7	−126	34	−8	$\boxed{-220}$
OCTOBER	82	9	73	−53	57	48	−172
NOVEMBER	67	4	63	10 RUN OFF COMMENCES	47	43	−129
DECEMBER	76	1	75	85	53	52	−77
JANUARY	56	1	55	140	39	38	−39
FEBRUARY	52	4	48	188	36	32	−7
MARCH	53	9	44	232	37	28	21 RUN OFF COMMENCES
YEAR	695	463		232	484		21

+ Evaporation calculated by the Penman formula for watered vegetation.
* Value for interception in conifer canopy.

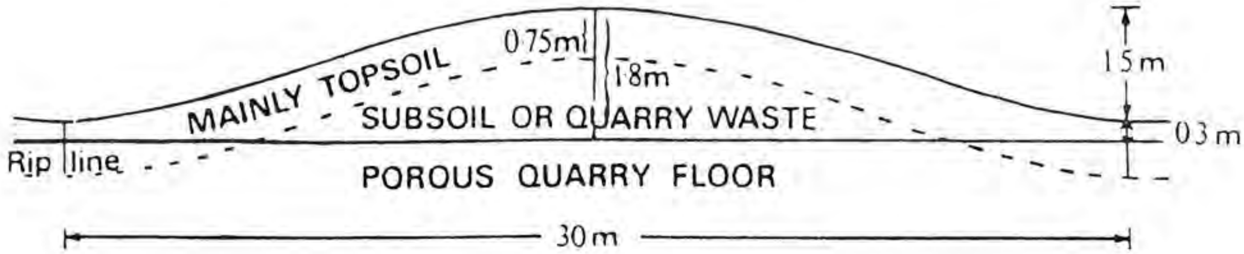


Fig 3 Landform for restoration over porous sand. Ridges ripped across by Caterpillar D8 with triple winged tines. Tool points at 75 cm. Vertical scale twice the horizontal.

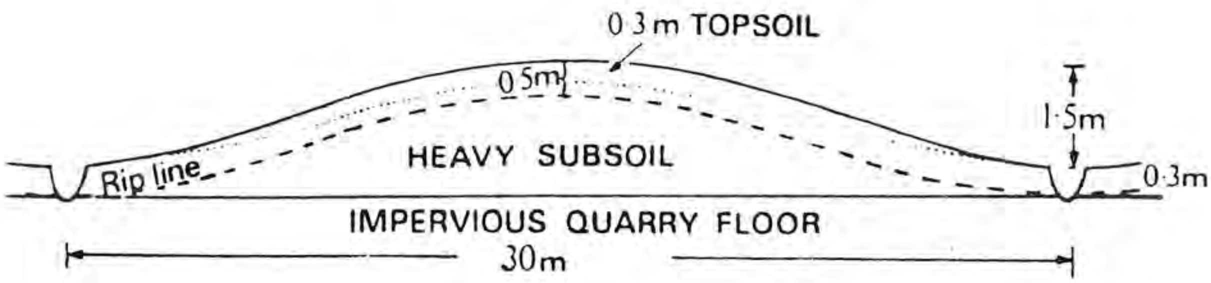


Fig 4 Landform for restoration over impervious material. Ripping as in fig 3 but tool point at 50 cm. Drains put in by side-acting digger. Vertical scale twice the horizontal.

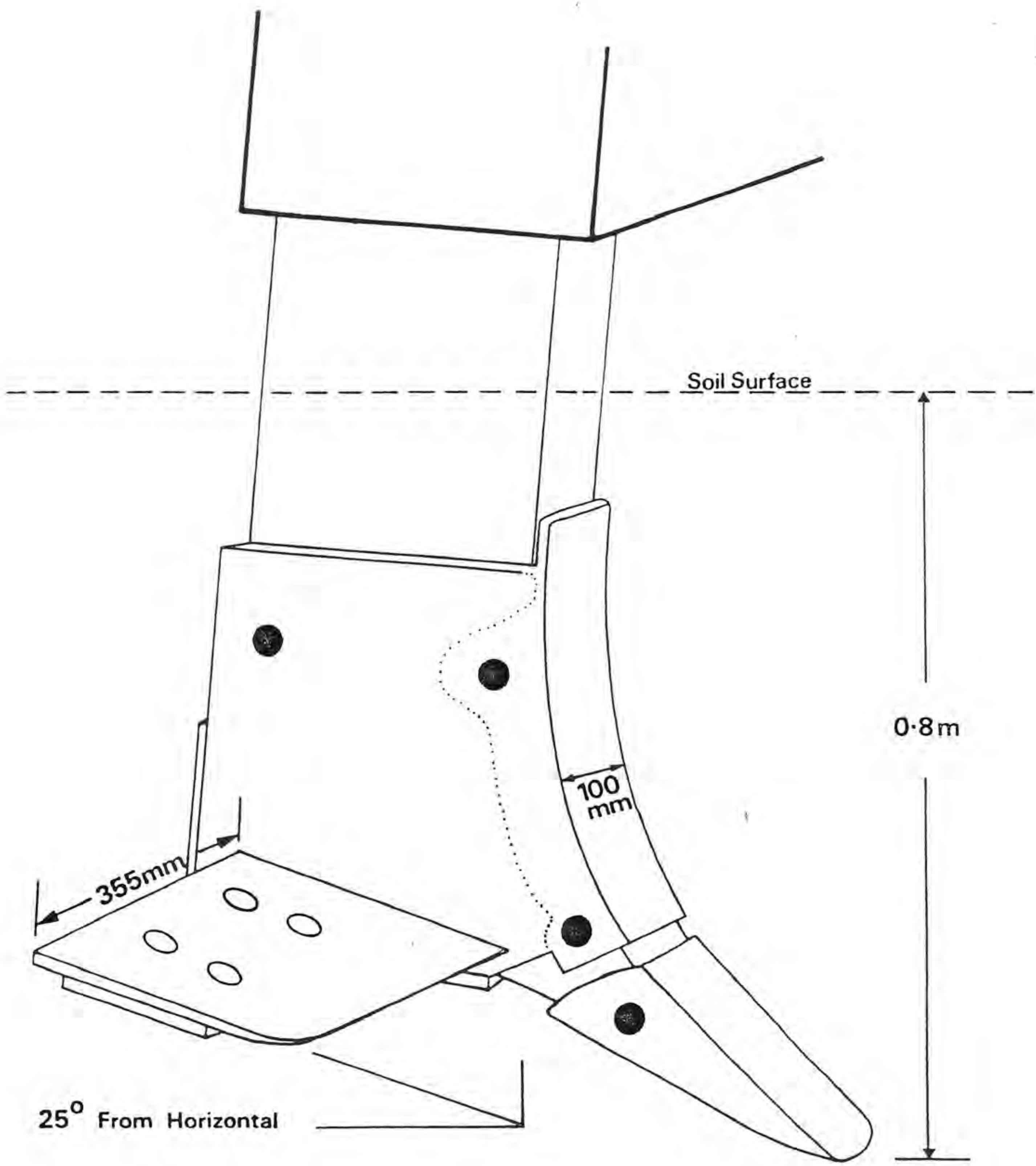
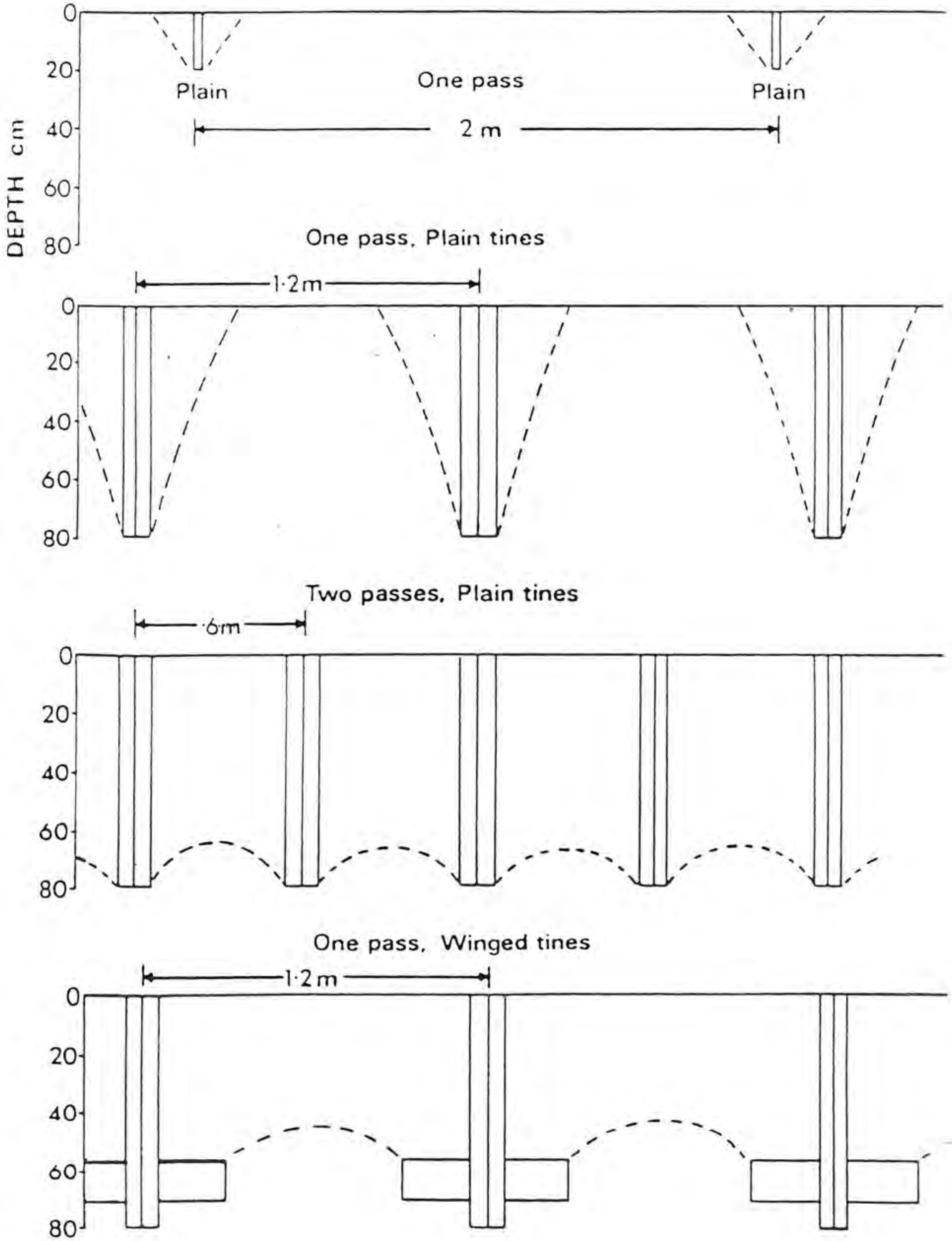


Fig 2 Current design of winged tine. The 25° angle was found to be the best compromise for resistance, disturbance and wear on the underside of the plate.

Degree of soil disturbance



CONTROL OF SURFACE WATER AND GROUNDWATER FOR TERRAIN STABILIZATION - LAKE LOUISE SKI AREA

F.B. CLARIDGE[1], T.L. DABROWSKI[2], M.V. THOMPSON[3]

1. Komex Consultants Ltd., Calgary
2. D.R. Piteau & Associates (Alberta) Limited, Calgary
3. Nanuk Engineering & Development, Cochrane

ABSTRACT

Skiing conditions at the Lake Louise Ski Area may be improved by the application of artificial snow. Concern has been expressed that artificial snow may contribute to the development of slope failures. Geotechnical and hydrological investigations indicate that the proposed surface water and groundwater control systems will reduce groundwater recharge. This will result in lowering the groundwater surface, contributing to an overall improvement in slope stability.

INTRODUCTION

In 1981, the Lake Louise Ski Area produced a Development Plan. This plan contained various components which were designed to improve the overall quality of skiing at Lake Louise. The principal component of the plan is artificial snowmaking. Parks Canada expressed concern that snowmaking would aggrevate existing terrain stability problems on the ski hill. A study to ameliorate these problems produced a surface and groundwater control system. This will stabilize slopes in areas where soil slumping has occurred, or is probable.

The area of emphasis for the study was the lower elevations - below the treeline - of Whitehore Mountain (Drawing 1) where snowmaking is proposed. Some slope instability, both natural and man-induced, exists throughout this area. Visible evidence of instability takes the form of surficial slumps. These are typically 30 to 50 m long, 20 m wide and 2 m deep. The instability of the glacial drift soil, which underlies the area, is related to the soil moisture condition, with failures almost always occurring within a saturated soil. The control of soil moisture content was achieved by lowering the groundwater surface in localized areas and by restricting groundwater recharge from water courses and springs.

TOPOGRAPHY AND SURFACE DRAINAGE

The gradient of the central ski runs varies from relatively gentle at the Whitehorn Mountain base to comparatively steep near the top of the ski runs. The terrain rises from an elevation of 1660 m at Whiskeyjack Lodge, at an average gradient of 5° to the base of the ski runs. From elevation 1700 m to 1860 m, slopes are approximately 14°, leveling to 10° towards the 1900 m elevation. The final rise to the top of the ski runs averages a slope of 20°. Some sections as steep as 30° are also encountered, particularly midway along the Juniper and Men's Downhill runs.

The primary contributors to surface flows on the Whitehorn face are two springs. One is located under, and the other just above the upper terminus of the Glacier chair. The precise location of these water sources, Triple Creek and Glacier Seep, are shown on Drawing 1. The streams originate at the 2100 m level and flow generally in the area of the ski runs. The two streams join in a swampy area located at the 1900 m level. The stream then flows to the 1700 m level where a portion enters a cistern or sump which eventually supplies water to Whiskeyjack Lodge. The remaining flow joins Fish Creek.

GENERAL GEOLOGICAL CONDITIONS

Bedrock Geology

Bedrock in the Whitehorn face consists of a number of sedimentary rock types belonging to the Corral Creek Formation. The major rock types are slate, sandstone, siltstone and conglomerate. In the upper slopes, where rock exposures have been mapped, bedding dips at between 30° and 70° toward the southwest. (Geological Survey of Canada, 1975).

Overburden Geology

Soil overburden consists of glacial till deposited during the Pleistocene Period. Although there is little subsurface information available to permit an interpretation of overburden thicknesses along the Whitehorn face, in general, the till deposit is thin (less than 5 m) near the 2135 m elevation and is relatively thick towards the bottom of the slope and the location of the Whiskeyjack Lodge.

GROUNDWATER CONDITIONS

The hydrogeological exploration indicates that the till varies significantly in the relative proportions of fine and coarse grained material. Therefore, the distribution of these variable permeability surficial deposits will have an important bearing on groundwater movement within the slopes (Drawing 2). Another important factor is the ability of the weathered bedrock surface to transmit water. Jointed indurated shale bedrock with iron staining on the joint surfaces indicates an appreciable groundwater flow at the bedrock surface. During drilling, a discharge of about 0.4 L/s (5 gpm) was air-lifted from the overburden-bedrock interface. Water moving downslope in the weathered bedrock is confined by the less permeable till deposits (high clay or silt content). However, where comparatively permeable tills are present (low clay or silt content), groundwater can selectively move under pressure up into the surficial deposits. This water can reach the ground surface, forming local swampy seepage zones (Drawing 2).

Groundwater is therefore moving downslope through two media. Firstly, through the more permeable of the till units. Secondly, through the bedrock, especially the weathered upper zone. Meltwater can recharge the weathered bedrock surface via sandy to gravelly tills in the upper slopes.

WHITEHORN SLOPE STABILITY

Parameters Used in Analysis

The primary soil properties required in the analysis of stability are the material density and drained strength parameters. The following parameters were used for the till:

a) Saturated density of 220 kg/m^3. This corresponds to a moisture content of 12%.

b) Effective stress strength parameters:

cohesion (c) = 19 kPa

friction angle (Ø) = 27°

Groundwater Assumptions

The level of the groundwater surface is expected to fluctuate within the upper 7.5 m of the soil overburden during the course of the year. Water levels are generally near their lowest point in the cycle during the month of March. Hence, higher levels are anticipated in late spring and early summer. To assist in understanding the importance of groundwater levels on the stability of critical slopes, a sensitivity analysis was conducted of stability as described in the following paragraphs.

Results

A series of calculations were made for the staility of a range of failure surfaces. The results are shown on Drawing 3. The analysis is generated for the steepest ski slope on Whitehorn (30°). For example, considering a depth of 6 m and the water surface at a depth of 4 m below the surface of the slope, a safety factor of 1.0 would result. If the water surface was any higher than this position, a failure would ensue at a depth of approximately 6 m, or less.

The stability analyses assumed a quasi-circular shaped failure surface. A generalized method of slices was used. This is applicable to both circular and non-circular slip surfaces. Utilizing an in-house computer program, GEOSLP, the failure geometry was analysed on a slice-by-slice basis, calculating driving and resisting forces for each slice. The factor of safety is proportional to the ratio of resisting to driving forces.

EFFECT OF DRAINAGE AND SNOWMAKING SYSTEMS ON STABILITY

Moisture Balance

Under current conditions, groundwater is recharged from higher elevations in the Whitehorn slope, as well as from direct precipitation. With the installation of the snowmaking system, additional moisture will be placed on the slope. This will contribute to the amount of incoming moisture during the spring melt period. On the other hand, it is possible to divert water which is re-entering the slope from springs emerging on the hillside at approximately elevation 2100 m and below. From a gauging measurement of the spring emerging near the level of the Whitehorn lodge, it is estimated that approximately 4.5 L/s (60 igpm) is flowing. By visual comparison, the other stream has a flow of approximately 3 L/s (40 igpm). These streams can be diverted away from the slope.

The balance between moisture which will be added from the snowmaking system, and which can be diverted, is shown conceptually on Drawing 4. The surface area considered is approximately 2 km x 0.5 km (10^6 m^2). The ski runs where additional snow will be placed are, in reality, only a small fraction of this surface area. The hydrological system is shown for two conditions. Firstly, under existing natural conditions. Secondly, with additional precipitation (artificial snow) over the whole area and with the new drainage system installed. The percentage figures for infiltration, evapotranspiration and runoff, and the amount of added snow cover, are selected to be highly conservative. A worst case scenario is therefore represented. As the potential groundwater drainage and surface water diversion (containment) exceed increased infiltration, the moisture condition of the slope will be improved.

Under natural conditions, the moisture input to the area per annum is 32 L/s (422 igpm, Drawing 4). This comprises 8 L/s (105 igpm) stream inflow and 24 L/s (317 igpm) precipitation. A conservative infiltration figure of 20% is assumed. This gives an infiltration rate of 6.4 L/s (84 igpm) on a yearly basis. An infiltration factor of 20% is highly conservative considering the local topography, geology, and potential evapotranspiration. The relatively steep slopes will enhance runoff. The presence of clay till as indicated by drilling, will also inhibit infiltration. Potential evaporation figures for the area actually exceed the precipitation figures (Hydrological Atlas of Canada, 1978). This gives an infiltration rate of 6.4 L/s (84 igpm) on a yearly basis.

With an added artificial snow cover, the moisture input is increased to 37.6 L/s (496 igpm, Drawing 4). The infiltration effectiveness of the stream inflow is conservatively reduced by 50% in response to diversion and containment. The moisture input is therefore made up of 3.7 L/s (49 igpm) stream inflows and 33.9 L/s (447 igpm) combined natural and artificial precipitation. At 20% infiltration, this gives the amount of water recharging the slope as 7.5 L/s (100 igpm). This represents an increase of 1.1 L/s (15 igpm) over natural conditions. However, improved drainage is calculated to reduce overall infiltration by 3.0 L/s (40 igpm). The result is a net improvement in the moisture balance of 1.9 L/s (25 igpm) on a yearly basis.

With the addition of an effective system of surface and subsurface drainage, it is anticipated that the water table can be depressed under most circumstances envisaged.

The proposed drainage system is relatively shallow compared with the depression in the water level required to assure slope stability in the critical areas. Lowering of the groundwater surface within the slope area will be a result of a reduction of groundwater recharge by interception of groundwater flow by the drains. Further reduction of groundwater recharge will be achieved by the diversion and containment of surface water.

Effect on Stability

If water levels are maintained at no higher than 6 m from the ground surface in the steepest portion of the Whitehorn slopes, the slopes will retain a minimum safety factor of 1.1, thereby ensuring stability.

PROPOSED DRAINAGE SYSTEM

Interception of Surface Drainage

The interception of surface water before it can recharge the groundwater is essential to stabilization of the steeper pitches on the Whitehorn face. There are three possible methods of preventing the surface water from contributing to the groundwater flow:

1. Intercept and divert the two streams at their highest elevation to a channel completely outside the ski runs;

2. Collect and contain the water from the two streams in a pipeline and convey it to cistern storage below the control/compressor building near Whitehorn Lodge;

3. Channelize the two streams in their existing courses and improve the culverts and streambeds to reduce infiltration into the subsurface soil.

All of the above measures will reduce icing areas on the slopes and will improve the quality of skiing on the Whitehorn face.

Subsurface Drainage System

French drains should be installed in steep, critical slopes where instability has occurred in the past, or there is evidence of incipient slumping (Drawing 1).

The design of a typical French drain is shown on Drawing 5. The design consists of filter gravel placed into a trench with dimensions 0.75 m wide by approximately 2-3 m deep. Filter cloth should be installed in the trench walls to prevent migration of silt fines from the native till into the filter gravel.

Supplementary Drainage Measures

The subsurface drainage system discussed above is anticipated to produce a significant impact on existing groundwater conditions. However, the system may require extension as indicated by the relative success achieved during its first year of operation.

Also, due to the presence of low permeability fine-grained tills locally, it may be unavoidable that some sections of the system may be less effective than elsewhere. In these circumstances, it may be necessary to drill sub-horizontal drainage holes to increase the effectiveness of the system in critical areas.

SUMMARY OF FINDINGS

The geological conditions underlying the Whitehorn slope and preventative measures being proposed for ensuring that slope stability is maintained after the introduction of snowmaking are summarized in the following:

1. The Whitehorn slopes are underlain by a relatively thin deposit of glacial till. This rests directly on shale bedrock. In the past, slumps have occurred within the till in steeper portions of Juniper run.

2. The till is markedly heterogeneous with the proportions of clay, silt, sand, gravel and boulders varying appreciably. The deposits are moderately dense, with relatively low natural moisture contents. This material has a relatively high undrained shear strength. However, the till is susceptible to failures in the steeper slopes if the groundwater surface should rise to certain levels. Susceptibility to failure in these critical slopes is examined in detail in the report.

3. Because of previous slumping in the Whitehorn face, a program of drainage interception is recommended. The small creek which is fed by a spring emerging from bedrock west of the Whitehorn Lodge should be diverted or contained. This creek is considered to be responsible to a large degree for the high water levels experienced in the slope locally. In addition to intercepting surface flows, subsurface drains should be installed in critical sections of the slopes to ensure that the water surface is depressed. Water levels should then be monitored

in the piezometers installed in the slope. If levels are not depressed sufficiently after the subdrains have been installed, it may be necessary to drill sub horizontal drainage holes in critical sections of the slope.

The necessity of providing supplementary drainage holes should be established after the performance of the recommended drainage system has been monitored during the first year of operation.

4. The additional amount of water infiltrating the slopes due to the proposed artificial snow-making is estimated at 1.1 L/s (15 igpm). However, the recommended surface and groundwater drainage system is estimated to reduce overall infiltration by 3.0 L/s (40 igpm). Hence, the drainage system will more than compensate for the effect that the snow-making system may have in raising water levels in the slope.

5. The surface and subsurface drainage systems should be installed in advance of constructing the water pipeline system. Trench excavation should proceed upwards from the toe of the slopes to assist in drainage. Trenching equipment should not be brought onto the slopes until satisfactory drainage has been achieved.

6. Flexibility should be exercised in determining the depth of the pipeline trench to be excavated. In dry ground, no difficulty is anticipated for conventional backhoes reaching the design depth. However, in wet ground, it may be difficult to excavate a stable trench. A shallow trench design is required in wet areas, whereby the trench depth would

be limited to approximately 1 m. Continuous water circulation and/or insulation would be necessary to prevent freezing. A further alternative would be to have the pipe heat traced through these areas.

7. Following construction, the work area should be levelled and re-vegetated, using established reclamation practices for the ski area.

ACKNOWLEDGEMENTS

The cooperation of the management and personnel of Skiing Louise Ltd. is greatfully achnowledged. Special contribution to this project was made by Messrs. C. Locke, J. Worrall and J. Buckingham.

The authors has many helpful discussions on various aspects of this study with Dr. B.F. Leeson, Mr. B. Beswick and Mr. C. Israelson of Environment Canada, Parks Canada.

Thanks are also extended to Mr. L.S. Lyness for assistance in the field work and data evaluation.

REFERENCES

Geological Survey of Canada, F.C. Taylor, 1975; Map 1428A.

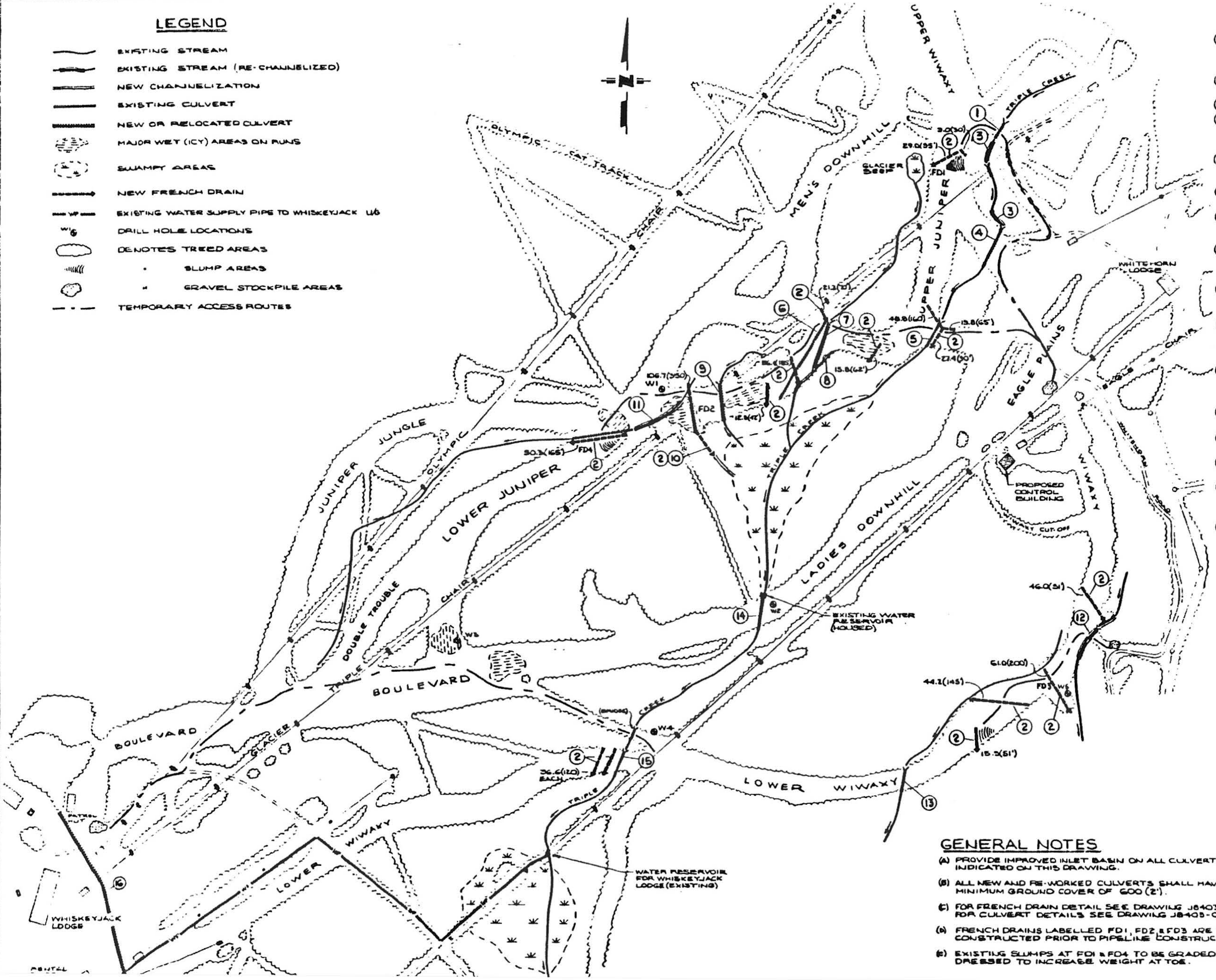
Hydrological Atlas of Canada, 1978.

Nanuk Engineering & Development Ltd., 1984; Preliminary Study for Skiing Louise Snowmaking System - Terrain Stability and Water Supply.

Nanuk Engineering & Development Ltd. and Komex Consultants Ltd., 1984; Report to Skiing Louise Ltd., Snowmaking System - Geotechnical Studies.

LEGEND

- EXISTING STREAM
- EXISTING STREAM (RE-CHANNELIZED)
- NEW CHANNELIZATION
- EXISTING CULVERT
- NEW OR RELOCATED CULVERT
- MAJOR WET (ICY) AREAS ON RUNS
- SWAMPY AREAS
- NEW FRENCH DRAIN
- EXISTING WATER SUPPLY PIPE TO WHISKEYJACK U/G
- DRILL HOLE LOCATIONS
- DENOTES TREED AREAS
- " SLUMP AREAS
- " GRAVEL STOCKPILE AREAS
- TEMPORARY ACCESS ROUTES



CONSTRUCTION METHODS

(1) REMOVE EXISTING PLYWOOD COVER OVER OPEN DITCH AND INSTALL 25.0m(82') OF 460ᶲ CULVERT FROM (6), BACKFILL AND IMPROVE INLET BASIN AS PER DRAWING J8403-03

(2) CONSTRUCT FRENCH DRAIN AS INDICATED ON THIS DRAWING AND AS PER DRAWING J8403-02

(3) RECHANNELIZE PORTION OF STREAM.

(4) (EXISTING 400ᶲ × 21.0(69') CULVERT, COVERED WITH LOGS.) REMOVE DEBRIS, ADD 7.0m (23') OF CULVERT TO UPPER END, BACKFILL ENTIRE CULVERT AND PROVIDE INLET BASIN

(5) REPLACE EXISTING 300ᶲ CULVERT WITH 30.0m(98') OF 460ᶲ CULVERT FROM (6) AND CONSTRUCT NEW INLET BASIN.

(6) REMOVE 460ᶲ × 170.0m(558') CULVERT AND RE-USE AS INDICATED

(7) CONSTRUCT 460ᶲ × 105.0m(345') CULVERT WITH IMPROVED INLET BASIN, USING 460ᶲ CULVERT FROM (6)

(8) (EXISTING SNOWMAKING POND) REMOVE BERM FROM AROUND POND AND RE-CHANNELIZE STREAM FROM ABOVE POND TO WHERE STREAM ENTERS TREES BELOW.

(9) REPLACE PLYWOOD COVERED TRENCH WITH 300ᶲ × 45.0(148') CULVERT (FROM LOCATION (5)). WITH IMPROVED INLET BASIN.

(10) ARRANGE SLOPE OF BOTTOM OF FRENCH DRAIN SUCH THAT DOWNSTREAM END IS APPROXIMATELY 600(2') BELOW EXISTING GROUND AND PROVIDE 30.0m (100') OF NEW CHANNEL FROM THIS POINT TOWARD TRIPLE CREEK.

(11) DEEPEN CHANNEL OF EXISTING STREAM TEMPORARILY TO REDUCE SURFACE WATER IN AREA DURING CONSTRUCTION. INSTALL IMPERVIOUS "PLUG" IN THIS TRENCH AFTER CONSTRUCTION.

(12) RE-CHANNELIZE STREAM AS INDICATED AND LOWER CULVERT.

(13) REPLACE EXISTING WOOD CRIB CULVERT WITH 460ᶲ × 40.0m(130') NEW STEEL CULVERT.

(14) RE-BUILD WOOD BOX CULVERT WITH REMOVEABLE PLANK COVER, SAME SIZE AS EXISTING.

(15) REMOVE AND REPLACE EXISTING 600ᶲ × 27.0(89') CULVERT USING SALVAGEABLE SECTIONS WHERE POSSIBLE AND INSTALL PREFABRICATED END SECTION ON INLET.

(16) IMPROVE FISH CREEK CONVEYANCE AND DRAINAGE AT OLYMPIC BASE

GENERAL NOTES

(A) PROVIDE IMPROVED INLET BASIN ON ALL CULVERTS INDICATED ON THIS DRAWING.

(B) ALL NEW AND RE-WORKED CULVERTS SHALL HAVE A MINIMUM GROUND COVER OF 600 (2').

(C) FOR FRENCH DRAIN DETAIL SEE DRAWING J8403-02 FOR CULVERT DETAILS SEE DRAWING J8403-03

(D) FRENCH DRAINS LABELLED FD1, FD2 & FD3 ARE TO BE CONSTRUCTED PRIOR TO PIPELINE CONSTRUCTION

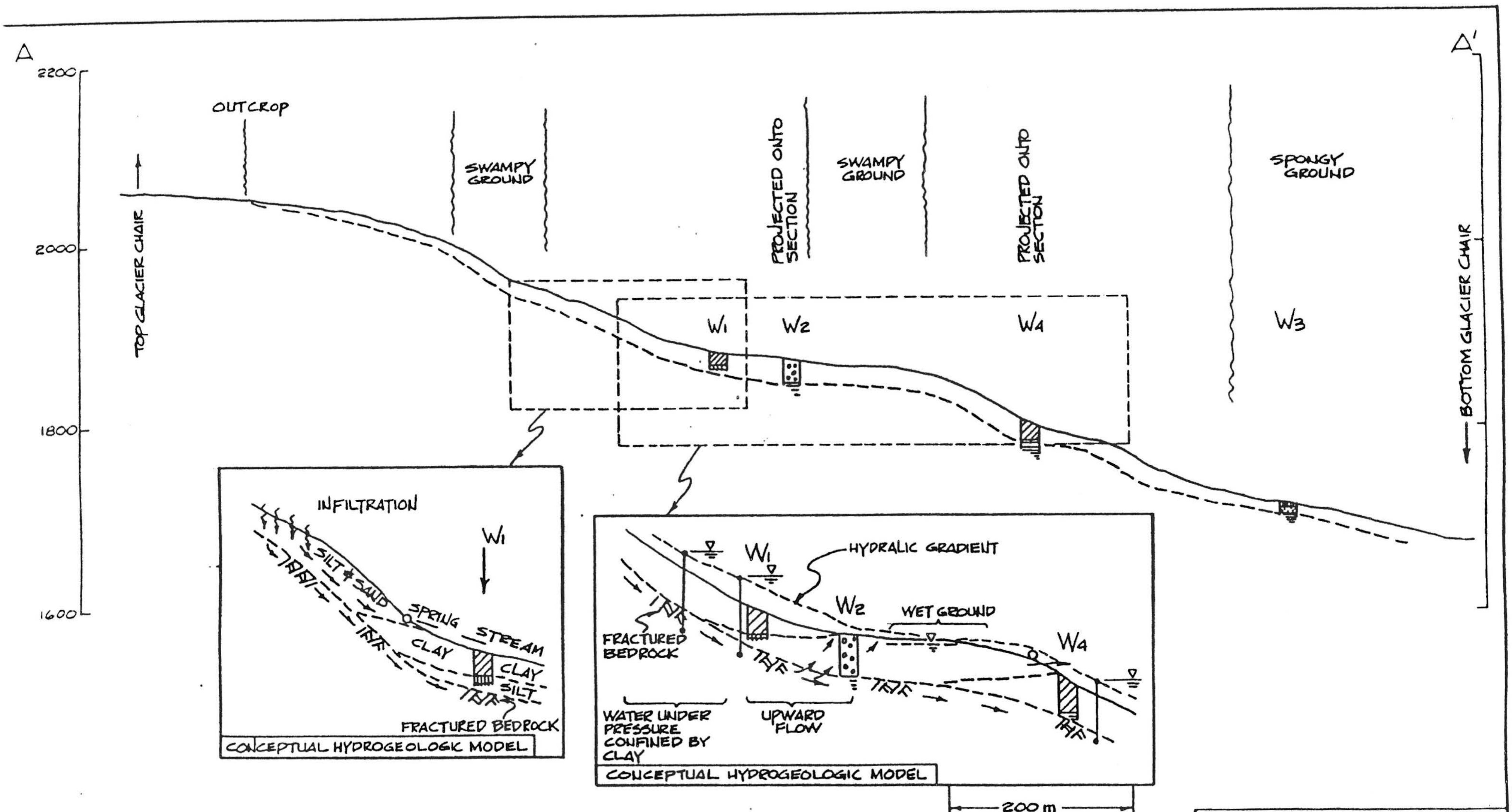
(E) EXISTING SLUMPS AT FD1 & FD4 TO BE GRADED AND DRESSED TO INCREASE WEIGHT AT TOE.

REV	DATE	DESCRIPTION
1	6 JUL 84	POST-RECONNAISSANCE REVISIONS

NANUK ENGINEERING & DEVELOPMENT
BOX 817 COCHRANE ALBERTA

SKIING LOUISE
WHITEHORN

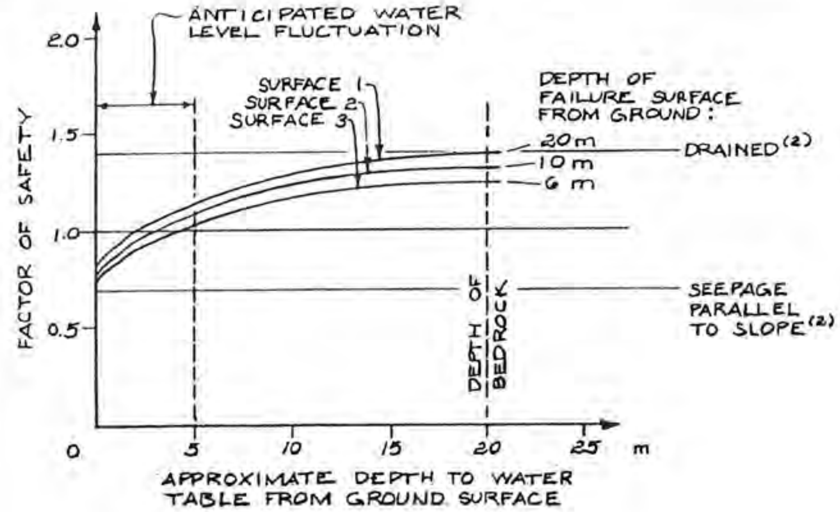
SURFACE & GROUNDWATER CONTROL SYSTEM

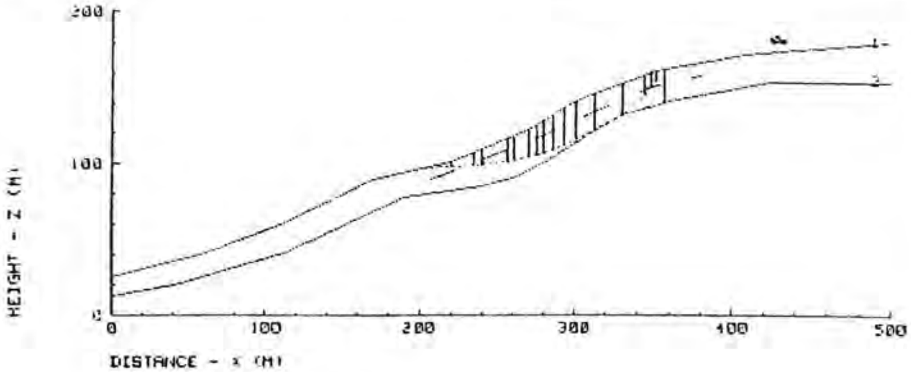


NOTE:
SUBSURFACE PROFILE BETWEEN CONTROL POINTS (DRILLHOLES) ARE INFERRED ONLY. ACTUAL GEOLOGIC CONDITIONS MAY THEREFORE VARY CONSIDERABLY FROM THE ABOVE INTERPRETATION.

1:4000

SKIING LOUISE
GEOTECHNICAL STUDIES
WHITEHORN - SLOPE PROFILE AND CONCEPTUAL HYDROGEOLOGICAL MODELS BENEATH GLACIER CHAIR
KOMEX — APR — 2





DISTANCE - X (M)

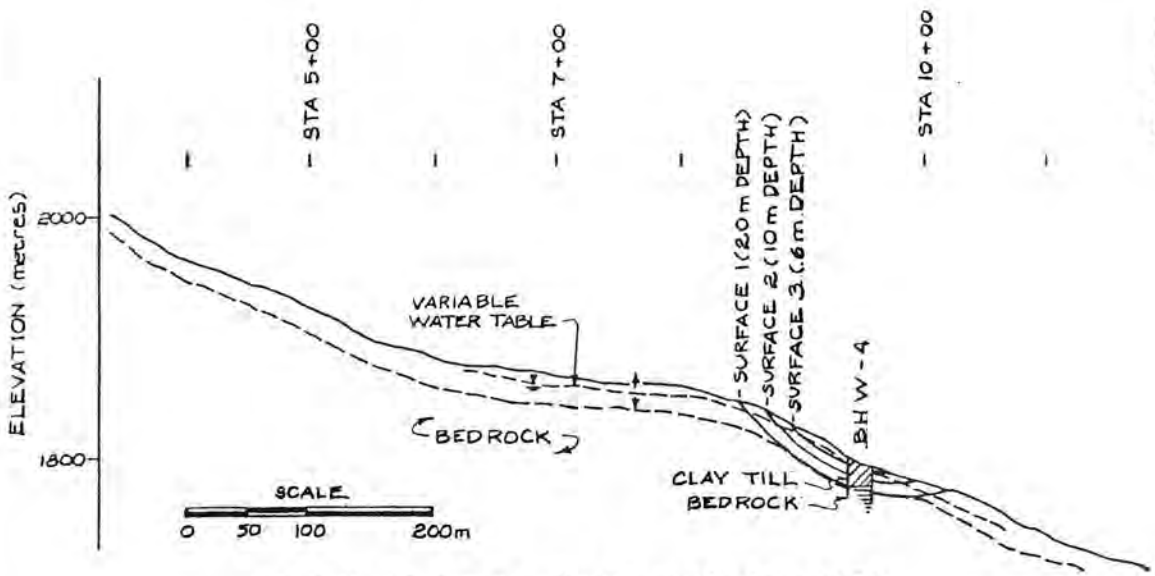
CORRECTION FACTOR: 1.056

FOS CONVERGENCE:

1.093
1.111
1.114

FINAL FOS = 1.114 RESISTING FORCE= 23001 DRIVING FORCE= 21801

EXAMPLE OF COMPUTER GENERATED DATA:
SURFACE 1, DEPTH OF WATER TABLE = 5m



SECTION OF GLACIER CHAIR FACING SE SLOPE
GEOMETRY AND SLOPE FAILURE VARIABLES

STRENGTH AND DENSITY PARAMETERS USED

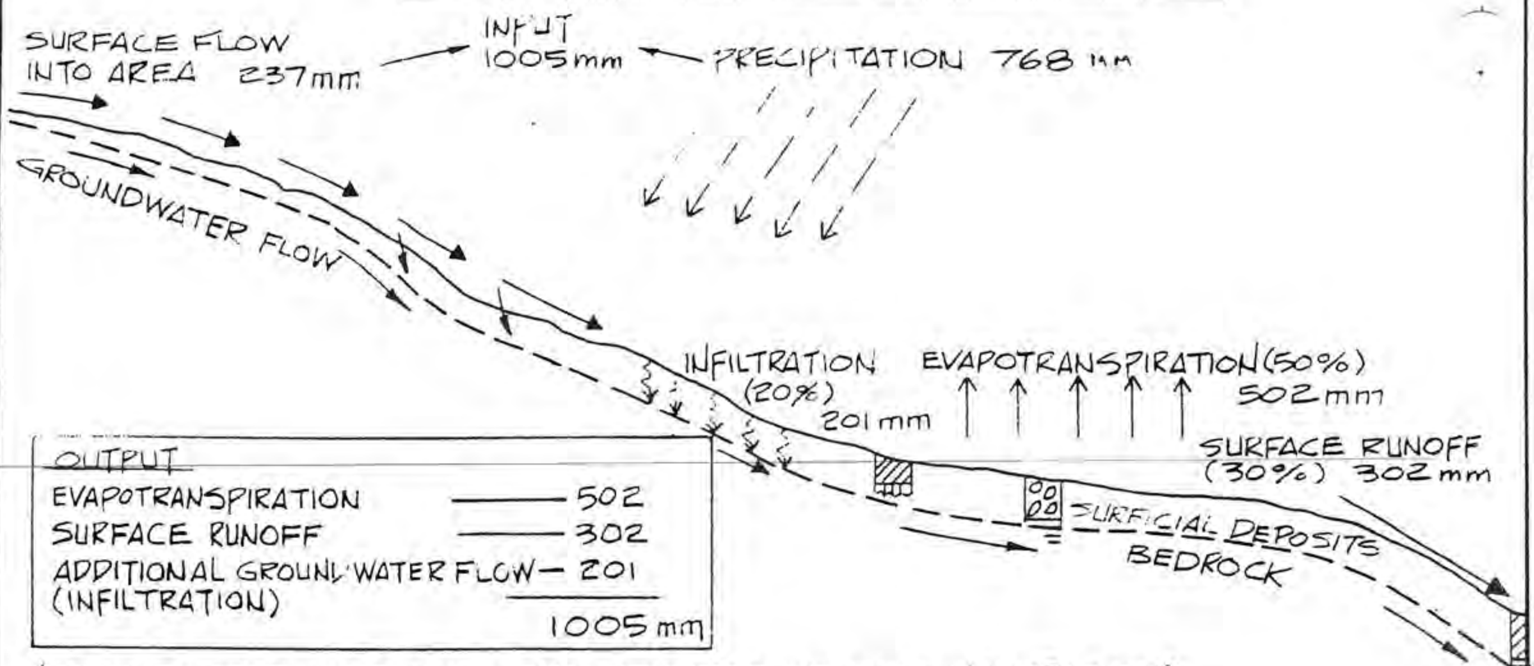
	UNIT WEIGHT (K_g/m^3)	COHESION (KPa)	FRICTION ANGLE (DEGREES)
CLAY TILL	2200	15	27 °

NOTES:

1) CONFIGURATIONS SHOWN ARE APPROXIMATE. ACTUAL SLOPE ANGLES AND DIMENSIONS MAY VARY.
2) THEORETICAL BOUNDARIES AS DEFINED BY INFINITE SLOPE ANALYSIS.

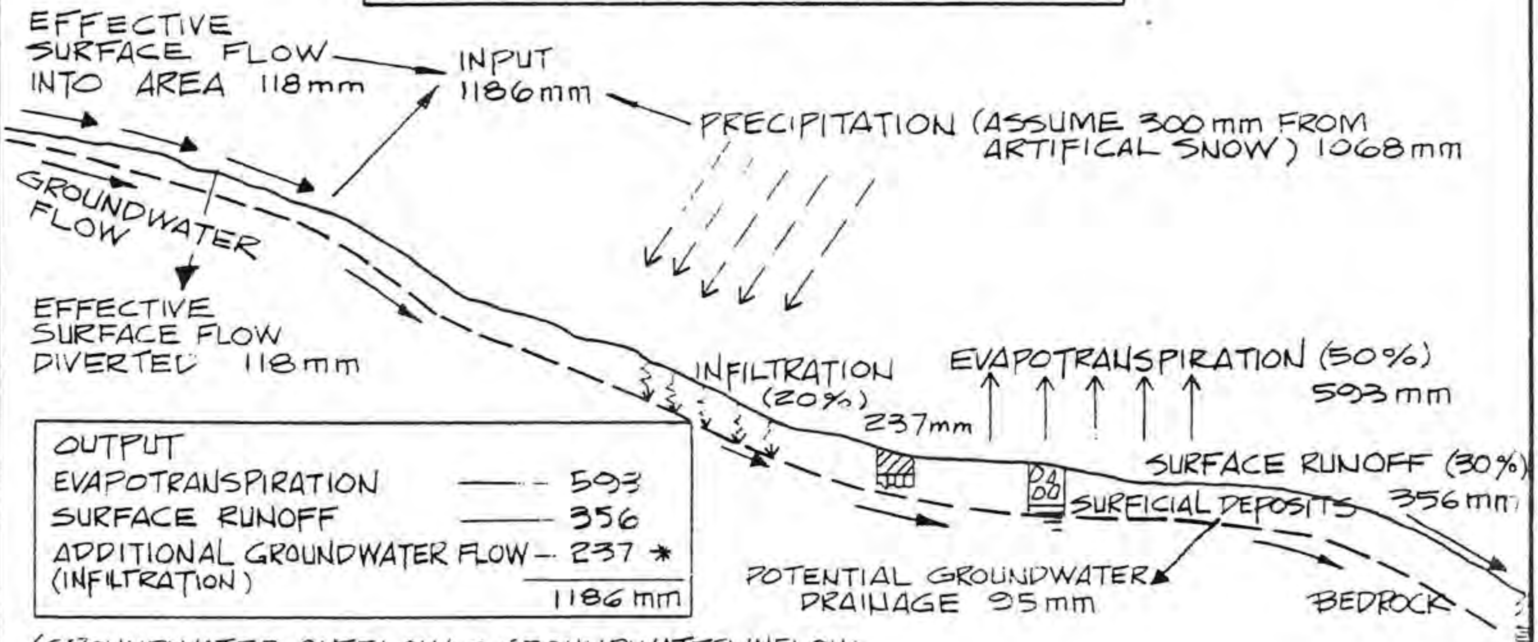
SKIING LOUISE
GEOTECHNICAL STUDIES
STABILITY ANALYSIS
KOMEX — APRIL '94 — 3

MOISTURE BALANCE : NATURAL CONDITIONS



(GROUNDWATER OUTFLOW = GROUNDWATER INFLOW + INFILTRATION)

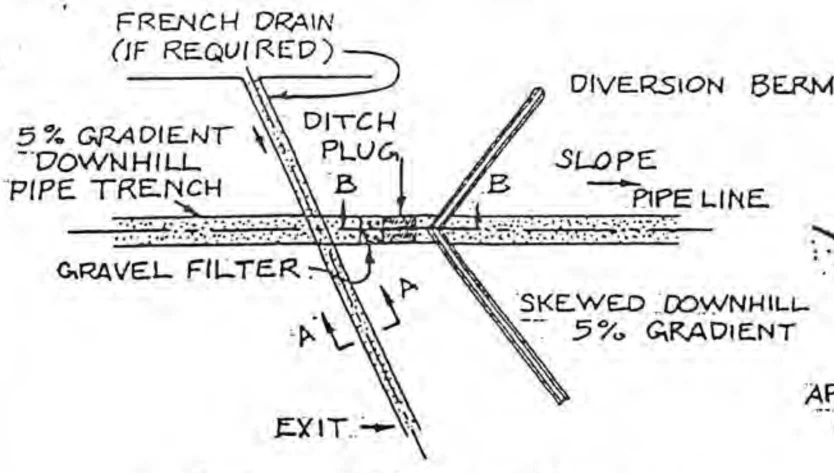
MOISTURE BALANCE : ADDITIONAL SNOW AND DRAINAGE SYSTEM



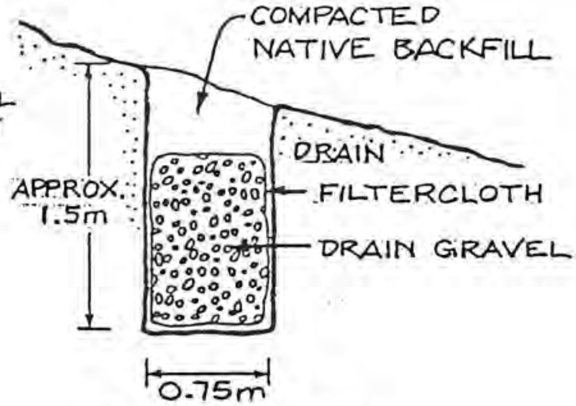
(GROUNDWATER OUTFLOW = GROUNDWATER INFLOW + INFILTRATION)

* MINUS NEW DRAINAGE : 237mm - 95mm = 142mm
(IMPROVEMENT OF 59mm)

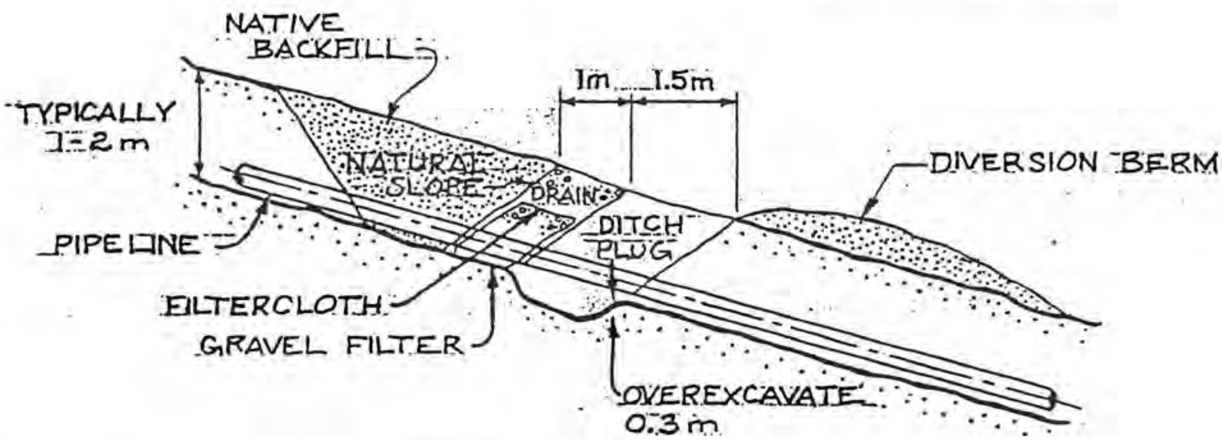
SKIING LOUISE			
GEOTECHNICAL STUDIES			
WHITEHORN - SCHEMATIC MOISTURE BALANCE FOR SLOPE UNDER NATURAL AND MODIFIED CONDITIONS			
KOMEX		APR. 84	4



TYPICAL LAYOUT OF FRENCH DRAINS AND DIVERSION BERMS



SECTION A-A
FRENCH DRAIN



SECTION B-B

NOTES:

1. DITCH PLUG TO CONSIST OF MIXTURE OF 15% BENTONITE AND SAND (BY WEIGHT).

2. FILTER FABRIC TO CONSIST OF POLYESTER, HAVING A MINIMUM WEIGHT OF 200 gm/m^2 AND A MINIMUM HYDRAULIC CONDUCTIVITY OF 1 mm/s.

3. DRAIN GRAVEL TO CONSIST OF FOLLOWING GRADATION: D100 = 40 mm LESS THAN 10% PASSING #200 SIEVE.

SKIING LOUISE			
GEOTECHNICAL STUDIES			
WHITEHORN DETAIL OF DIVERSION BERMS & FRENCH DRAINS			
KOMEX	MWT	APR. 84	5

MONTANE GRASSLAND REVEGETATION TRIALS

by

Donald M. Wishart, M.Sc., P.Ag.

Mutrie-Wishart Environmental Consultants

Calgary, Alberta

ABSTRACT

Revegetation trials were established in 1977 on a disturbed montane grassland in Jasper National Park, Alberta. The trials were designed to test the effectiveness of topdressing, fertilizer and seeding method treatments to establish native vegetation cover.

Ground cover and yield responded negatively to topdressing with either peat or with loamy sand similar to the native soil. Positive results were achieved by fertilizing at the time of seeding. These improvements have persisted, indicating that the nutrients are being cycled. Method of seeding did not significantly affect ground cover.

The results indicate that, if weather conditions are suitable, seedbed tillage and broadcast seeding alone can be sufficient to establish a productive native community in a montane environment.

1.0 INTRODUCTION

Areas of montane grassland are not extensive in Canada. Alberta's montane grasslands are confined to the mountain parks. They provide critical wildlife habitat and, because of their limited extent, have significant interpretive and educational values. However, development pressures, such as those recently realized in Banff National Park, have eliminated or disturbed some of these grasslands. It is important that techniques be developed to encourage the re-establishment of these grasslands after disturbance.

2.0 ECOLOGICAL DESCRIPTION

As the name implies, montane grasslands have a very open physiognomy. Ground cover is variable and bare ground is not uncommon. Vegetation tends to form localized communities in relation to subtle microsite changes.

Montane grasslands are characteristically comprised of drought tolerant bunch-grasses and other plants which increase in abundance under heavy grazing. Research has shown that biomass production, seed quantity and viability are all inherently low (Stringer, 1969; Walker et al., 1977).

Montane grasslands have developed largely in response to prevailing dry environments. Moisture deficiencies related to coarse, rapidly drained soils characteristic of these grasslands are compounded by frequent occurrence of warm foehn winds which result in marked snow ablation, rapid snowmelt and runoff in spring and high rates of evapotranspiration in summer. In normal years, the montane grasslands of Alberta's mountain parks have moisture deficits from late June until late October totalling 110 mm and soil water potential is often below -15 bars (nominal permanent wilting point) for at least one third of the growing season (Stringer, 1969; Hettinger, 1975).

Alberta's montane grasslands characteristically experience a short growing season (less than 90 days). Soils are generally nutrient poor (less than 5 ppm of available nitrogen and phosphorus), strongly alkaline (pH 8.0 to 8.8) and highly calcareous (greater than 15 percent free lime). The grasslands are also subject to the combined effects of heavy grazing, browsing and trampling by native ungulates.

3.0 LITERATURE REVIEW

The site factors which characterize Alberta's montane grasslands make revegetation problematic. One obvious means of overcoming undesirable characteristics of the soil medium is to topdress the site with a more suitable material. The addition of peat to coarse-textured soils has been shown to increase moisture holding capacity (Stevenson, 1974; Fedkenheuer, 1979). However, loamy sands such as those indigenous to montane grasslands have also been successfully used as topdressing to improve revegetative success on arid grasslands (Yamamoto, 1975; DePuit and Coenenberg, 1979).

Fertilization is a proven method of restoring fertility to nutrient poor sites and in many cases revegetation has been completely unsuccessful without addition of fertilizer at the time of seeding (Vogel, 1973; Curry, 1975). Furthermore, by adding an acid forming fertilizer such as ammonium sulfate, it is possible to counteract the adverse effect of alkalinity.

The success of revegetation efforts can also be greatly influenced by the method of seeding as demonstrated by Walquist et al. (1975) and DePuit and Coenenberg (1979). Raking or packing the seed into the seedbed or covering the seed with mulch reduces desiccation of germinating seeds and thereby minimizes the effect of low soil moisture levels (Russell, 1973; Johnston and Smoliak, 1977).

4.0 METHODS

In order to test the effectiveness of topdressing, fertilizing and seeding method techniques, field and greenhouse trials were conducted. A pipeline right-of-way in Jasper National Park, adjacent to Jasper Lake, was selected as the site for the revegetation trials. The pipeline was constructed in 1952 and over the ensuing 25 years, the study site had remained generally void of vegetation. No attempt had been made to conserve topsoil during construction or to reclaim the right-of-way afterwards. Wind erosion had left approximately half of the ground surface covered with gravel size material. Mean plant cover was 9.5 percent relative to 80.0 percent on adjacent undisturbed grasslands.

The logistics involved in applying four independent variables (topdressing, fertilizer, seeding methods and plant materials) necessitated the use of a split-plot experimental design. In the spring of 1977, the site was divided into four replications (rows) and then further subdivided into four levels of plot units which represented the four independent variables (Figure 1). The plots were rototilled and hand raked to create a level seedbed.

Fibric to mesic peat derived from feather mosses and sphagnum mosses was applied to one third of the plots to a 10.0 cm depth. One third of the plots were topdressed with 7.5 cm of loamy sand textured, strongly calcareous, aeolian material. The loamy sand had properties very similar to those of the undisturbed soils adjacent to the study site (Table 1). The remaining plots were not topdressed.

One half of the topdressing plots were fertilized with 16-20-0 + 14%S while the other half were not fertilized. The fertilizer was broadcast at 785 kg/ha.

The fertilizer treatments were further divided into four seeding method units. The seeding methods tested were:

1. broadcast seeding;
2. hand raking the seed into the seedbed;
3. packing the seed into the seedbed; and
4. covering the seed with a cellulose fibre hydromulch at 1675 kg/ha.

FIGURE 1: Schematic Field Experiment Plot Design

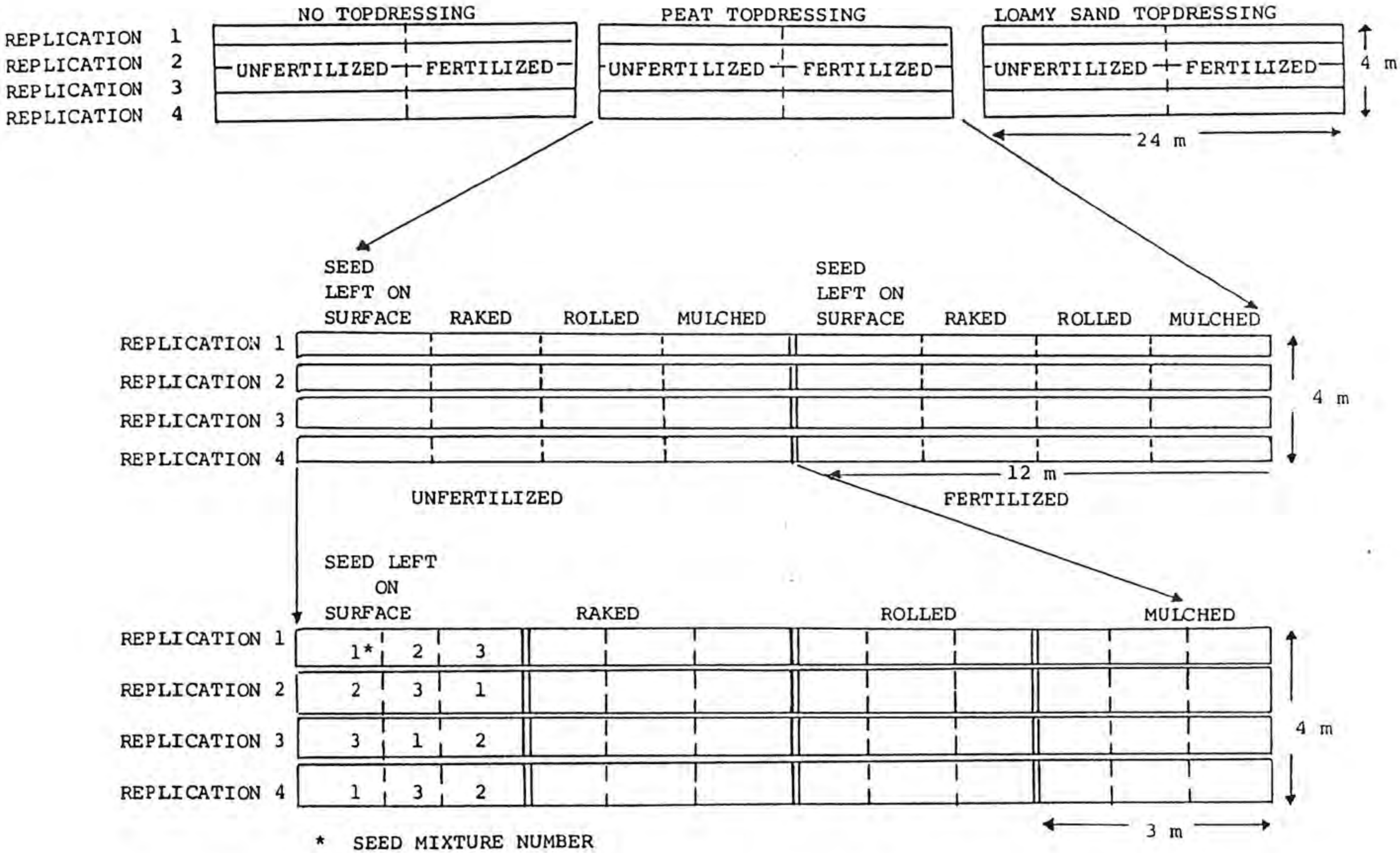


TABLE 1: Soil Test Results for Soils and Topdressing Prior to Treatment [1]

MATERIAL	SAMPLE DEPTH (cm)	AVAILABLE PLANT NUTRIENTS[2] (ppm) (N)	(P)	(K)	SULFUR[3]	SOIL REACTION (pH)	SOIL CONDUC-TIVITY (mmhos)	SULFATES	SODIUM	FREE LIME[3]	ORGANIC MATTER[3]	TEXTURE[4]
Study Site Soil	0-15	1	0	113	M-	8.3	0.4	NIL	L-	H+	L	SL
	16-30	0.5	0	66	M-	8.8	0.4	NIL	L-	H+	L	SL
Adjacent Undisturbed Soil	0-15	2	0	137	M	8.2	0.4	NIL	L-	H+	L	SL
	16-30	51	0	107	M	8.7	1.1	NIL	L+	H+	L+	L
Feathermoss & Sphagnum Peat Topdressing	N/A	1.5	0	42	M+	5.2	0.4	NIL	L-	L	H+	O
Loamy Sand Topdressing	N/A	0.5	0	59	L	8.0	0.3	NIL	L-	M+	L	LS

[1] Samples taken June 11, 1977

[2] N = Nitrogen
P = Phosphorus
K = Potassium

[3] Ranges are those of Alberta Agriculture Soil and Feed Testing Laboratory
Sulfur: L=1.1-2ppm, M=5.1-8ppm, M+=8.1-12ppm
Sodium: L=0-35ppm, L+=70.5-105ppm
Free lime: L=<1%, M+=6-8%, H+=>15%
Organic Matter: L=<1%, L+=1.1-2%, H+=>10%

[4] SL=Sandy loam, L=Loam, O=Organic, LS=Loamy Sand

The seeding method units were ultimately divided into one square metre plots to which three seed mixtures comprised of 16 native plant species were applied at a rate of 20 kg/ha (Table 2).

Research was designed to assess the response of plant species to the various treatments. However, these complex relationships are beyond the scope of this paper. For further information, see Wishart (1983).

In 1977 and 1978, data regarding percent ground cover, average plant height, vigor, soil fertility and grazing at the trial sites were collected by the author (Wishart, 1983). Ground cover data were analyzed using multiple analysis of variance. Treatments that were statistically significant using F table values at one percent level were compared using Duncan's Multiple Range Tests ($P \leq 0.01$).

The field trial studies were supplemented by greenhouse trials to determine the effect of temperature and moisture on topdressing and fertilizer treatments. Plant height and biomass data were analyzed using the same methods as those of the field trials.

In 1979 and 1980, Parks Canada collected similar field data but did not conduct statistical analyses (Harrison, 1979, Parks Canada, 1981, ed.). The author revisited the site in 1984 and the results of these qualitative assessments are included in the results.

TABLE 2: Plant Materials Used in Field Experiments

Species	Origin of Seed Stock	Native to Study Site Area	Drought Tolerant	Alkaline Tolerant	Nitrogen Fixer
Juniperus horizontalis Moench.	Kooteney Plains, Alberta	Yes[1]	Yes	Yes	No
Agropyron riparium Scribn. & Smith.	Oregon (cv. Sodar)	Yes[1]	Yes	Yes	No
Agropyron trachycaulum (Link) Malte	Beaverlodge, Alberta	Yes[1]	Yes	Yes	No
Agropyron sp.	Beaverlodge, Alberta	--[1]	--	--	No
Agrostis stolonifera L.	Poland	No	No	--	No
Elymus innovatus Beal.	Ft. St. John, B.C.	Yes[3]	No	--	No
Festuca saximontana Rydb.	Kootenay Plains, Alberta	Yes[1]	Yes	--	No
Koeleria cristata (L.) Pers.	Peace River, Alberta	Yes[2]	Yes	Yes	No
Poa alpina #1 L.	Pine Pass, B.C.	No	Yes	Yes	No
Poa alpina #2 L.	Unknown	No	Yes	Yes	No
Poa pratensis L.	Palmer, Alaska	Yes[1]	Yes	Yes	No
Rosa acicularis Lindl.	Cypress Hills, Alberta	Yes[3]	Yes	Yes	No
Astragalus sp.	Kootenay Plains, Alberta	--	--	--	Yes
Hedysarum alpinum L.	Peers, Alberta	Yes[2]	Yes	Yes	Yes
Hedysarum mackenzii Richards.	Haines Jct., Yukon	Yes[1]	Yes	Yes	Yes
Elaeagnus commutata Bernh.	High Level, Alberta	Yes[1]	Yes	--	Yes

[1] Identified by Stringer (1969).

[2] Identified by Hettinger (1975).

[3] Identified by Wells *et al.* (1978)

5.0 RESULTS AND DISCUSSION

5.1 General

Weather conditions for the first two growing seasons were more favourable to the establishment of vegetation than the long term average. Precipitation was 57 percent above the 30 year mean for the 1977 and 1978 growing seasons while temperatures were 2.1°C below average. These factors produced a more favourable soil moisture regime during the critical establishment period than normally exists and likely influenced the effectiveness of the various treatments.

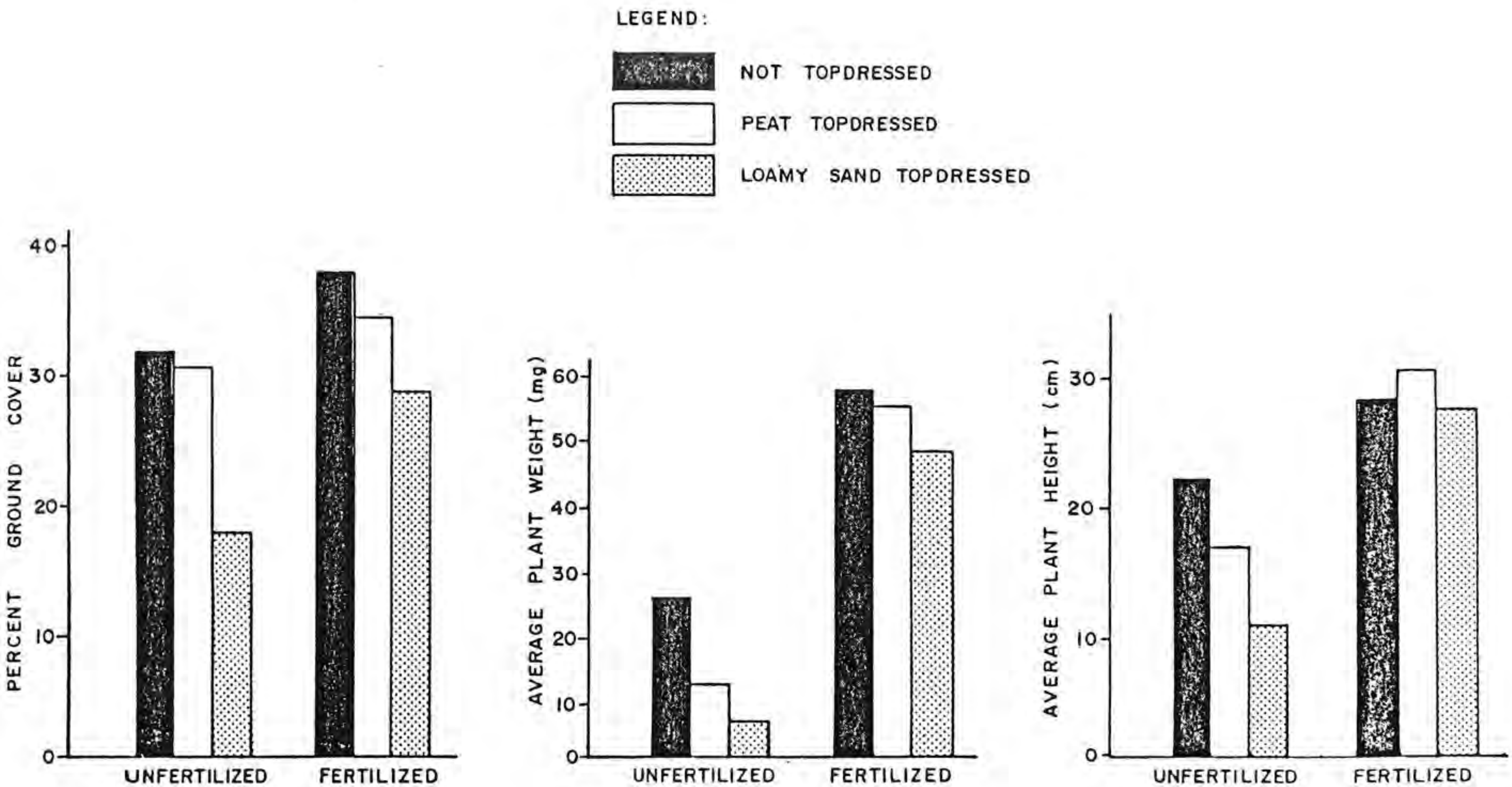
Emerged seedlings were observed at the field trial site four weeks after seeding and had produced approximately 20 percent ground cover by the end of the first growing season. Ground cover reached 30 percent by the end of the second growing season and 65 percent seven years after seeding.

5.2 Topdressing

Topdressing the seedbed was not beneficial (Figure 2). While soil analyses were unable to detect significant differences, greenhouse experiments demonstrated that both peat and loamy sand topdressings were less fertile than the original soils. Lower fertility was likely the major cause of the negative results from both topdressings.

The peat topdressing was probably too shallow to have significantly improved soil moisture levels. Research by Logan (1978) and Simard (1968)

FIGURE 2: Effect of Topdressing and Fertilizer Treatments on Ground Cover in Field Experiments and Plant Weight and Height in Greenhouse Experiments



indicates that somewhere between 25 and 66 cm may be a minimum depth at which peat must be applied to improve soil moisture and plant growth in the long term. Above-average precipitation probably overcame whatever beneficial effects on moisture-holding capability that the peat may have produced while plants became established. A delay in plant development was also noted on soils topdressed with peat. The delay was attributed to cooler spring soil temperatures which result from greater moisture levels. Significant winter kill was recorded in 1980 (Parks Canada, 1981, ed.) and may have been a result of this delayed plant maturity.

Applying loamy sand topdressing did little to improve the physical characteristics of the soil surface since simply rototilling the site had buried much of the surficial gravel that had inhibited natural revegetation. Consequently, the net effect of the loamy sand topdressing was to decrease fertility.

5.3 Fertilizer

Applying fertilizer significantly improved seed production, plant maturity rates, ground cover and plant biomass. Fertilizing increased ground cover 7 percent overall in the second year and increases in ground cover from fertilization did not diminish with time. Although soil tests indicated that the applied nutrients had become almost completely unavailable (Table 3) it is probable that fertilization encouraged the development of a more productive plant-nutrient cycle, whereby increases in

TABLE 3: Soil Test Results for Topdressing and Fertilizer Treatment Plots [1]

MATERIAL	SAMPLE DEPTH (cm)	AVAILABLE PLANT NUTRIENTS[2] (ppm) (N)	(P)	(K)	SULFUR[3]	SOIL REACTION (pH)	SOIL CONDUC -TIVITY (mmhos)	SULFATES	SODIUM	FREE LIME	ORGANIC MATTER[3]	TEXTURE[4]
No Topdressing No Fertilizer	0-15	1.5	0.5	109	L+	8.2	0.4	NIL	L-	H+	L+	SL
	16-30	0.5	0	62	L+	8.1	0.4	NIL	L-	H+	L+	SL
No Topdressing Fertilized	0-15	1	0.5	141	L+	8.2	0.4	NIL	L-	H+	L+	SL
	16-30	4.5	0.5	67	M-	8.4	0.4	NIL	L-	H+	L+	SL
Peat Topdressing No Fertilizer	0-15	1.5	0	108	M	8.0	0.4	NIL	L-	H-	H	O
	16-30	1	0	85	M	8.1	0.4	NIL	L-	H+	L+	SL
Peat Topdressing Fertilized	0-15	1.5	1.5	24	M+	7.8	0.4	NIL	L-	M+	H	O
	16-30	0.5	0.5	52	M+	8.2	0.3	NIL	L-	H+	L+	SL
Loamy Sand Topdressing No Fertilizer	0-15	0.5	0.5	57	L	8.5	0.3	NIL	L-	H+	L	LS
	16-30	0.5	0	72	L	8.4	0.2	NIL	L-	H+	L	SL
Loamy Sand Topdressing Fertilized	0-15	0.5	0	64	L+	8.3	0.3	NIL	L-	H+	L	LS
	16-30	0.5	0	65	M-	8.4	0.3	NIL	L-	H+	L	SL

[1] Samples taken September 4, 1978

[2] N = Nitrogen
P = Phosphorus
K = Potassium

[3] Ranges are those of Alberta Agriculture Soil and Feed Testing Laboratory
Sulfur: L=1.1-2ppm, L+=2.1-3ppm, M-=3.1-5ppm, M=5.1-8ppm, M+=8.1-12ppm
Sodium: L-=0-35ppm
Free Lime: M+=6-8%, H-=8-10%, H+=>15%
Organic Matter: L=<1%, L+=1.1-2%, H=8-10%

[4] SL=Sandy Loam, L=Loam, O=Organic, LS=Loamy Sand

detrital input equaled increases in mineralization or organic matter. All plant species showed a positive response to fertilization, including legumes.

Some of the fertilizer was absorbed by the growing plants. However, a significant amount of ammonium nitrogen was likely lost by volatization of ammonia which occurs as ammonium salts contact aqueous alkaline media.

Much of the applied phosphorus probably formed calcium compounds with low solubilities, a common fate of phosphorus in alkaline soil. Banding the phosphorus may have been a more appropriate method of application.

Within two years of application of a large quantity of acid-forming fertilizer, no decrease in soil pH could be detected. This is likely attributable to a loss of acid-forming material from volatization and leaching of fertilizer in conjunction with the large soil reservoir of free lime.

5.4 Seeding Methods

The method of seeding did not affect overall percent ground cover. Differences in plant establishment in the first growing season and in the early part of the second were noted. However, encroachment of established vegetation overcame the differences in a relatively short period of time.

Mulching was the poorest overall seeding method, probably because the mulch retards the rate of soil warming in spring and available nutrients become immobilized by microorganisms decomposing the organic matter.

Covering the fertilizer by raking it into the seedbed or by mulching produced a very pronounced increase in ground cover and plant biomass relative to unfertilized plots of the same seeding methods. This effect is likely due to an inhibition of volatization of ammonium fertilizer.

6.0 CONCLUSIONS

Simply broadcasting seed onto an unamended, rototilled surface produced ground cover of 35 percent after two growing seasons which was only 5 percent less than the best overall treatment, fertilizing and packing the seed. Seven years after seeding, these unamended plots where seed was broadcast still have excellent cover, which indicates that the gravelly seedbed prior to tillage and a lack of sufficient seed cast from adjacent grasslands were major limiting factors to natural secondary succession.

The results obtained from these field trials indicate the possibility of rapid establishment of a productive native plant community in a harsh mountain environment. If weather conditions are favourable while the plants become established, proper seedbed tillage and broadcast seeding alone can be sufficient to successfully establish ground cover. However, revegetation success can be enhanced by applying a suitable fertilizer composition at the time of seeding.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance and co-operation of Parks Canada, Trans Mountain Pipelines, Kitimat Pipelines, and the Department of Forest Science, University of Alberta.

LITERATURE CITED

Curry, R.R., 1975. Biogeochemical limitations of western reclamation: the high Northern Great Plains example. In: M.K. Wali (ed.), Practices and problems of land reclamation in Western North America. Proceedings of a symposium held in Grand Forks, North Dakota, January 20-21, 1975. Univ. of North Dakota Press, Grand Forks, North Dakota. pp. 18-47.

DePuit, E.J. and J.G. Coenenberg, 1979. Methods for establishment of native plant communities on topsoiled coal stripmine spoils in the Northern Great Plains. Reclam. Rev. 2: 75-83.

Fedkenheuer, A.W., 1979. Building soils using Athabasca Oil Sands tailings and soil amendments. In: Proceedings of fourth annual meeting, Canadian Land Reclamation Association, 13-15 August, 1979, Regina, Saskatchewan. Canadian Land Reclamation Association, Guelph, Ontario. pp. 175-195.

Harrison, G., 1979. Revegetation research: Windy Point, Jasper National Park. Natural History Research Division, Parks Canada. 22 pp.

Hettinger, L.R., 1975. Vegetation of the Vine Creek drainage basin, Jasper National Park. Ph.D. thesis, Department of Botany, Univ. of Alberta, Edmonton, Alberta, unpublished. 276 pp.

Johnston, A. and S. Smoliak, 1977. Principles of forage establishment. Alberta Agriculture, Edmonton, Alberta. Agdex 120/22-1. 3 pp.

Logan, R.J., 1978. Peat as a soil amendment for tailing sand reclamation. M.Sc. thesis, Department of Soil Science, Univ. of Alberta, Edmonton, Alberta, unpublished. 202 pp.

Parks Canada, 1981 (in Edit). Revegetation research: Windy Point, Jasper National Park. Natural History Research Division, Parks Canada. 29 pp.

Russell, E.W., 1973. Soil conditions and plant growth. 10th edition. Longman Group Ltd., Toronto, Ontario. 849 pp.

Simard, A., 1968. Studies carried out on some agricultural uses of peat. In: C. LaFleur and J. Butler (eds.), Proceedings of the third International peat congress, Quebec, Quebec. National Research Council, Ottawa, Ontario. pp. 343-344.

Stevenson, D.S., 1974. Influence of peat moss on soil water retention for plants. Can. J. Soil Sci. 54: 109-110.

Stringer, P.W., 1969. An ecological study of grasslands at low elevations in Banff, Jasper and Waterton National Parks. Ph.D. thesis, Department of Botany, Univ. of Alberta, Edmonton, Alberta, unpublished. 341 pp.

Vogel, W.G., 1973. The effect of herbaceous vegetation on survival and growth of trees planted on coal mine spoils. In: Proceedings of first research and applied technology symposium on mined land reclamation, Pittsburgh, Pennsylvania, March 7-8, 1973. National Coal Association, Washington, D.C. pp. 197-207.

Walker, D.G., R.S. Sadasiviah and J. Weijer, 1977. The utilization and genetic improvement of native Alberta grasses from the eastern slopes of the Rocky Mountains. Department of Genetics, Univ. of Alberta, Edmonton, Alberta, unpublished. 52 pp.

Walquist, B.T., R.L. Dressler and W. Sowards, 1975. Mined-land revegetation without supplemental irrigation on the arid southwest. In: Proceedings of third symposium on surface mining and reclamation, Louisville, kentucky, October 21-23, 1975. National Coal Association, Washington, D.C. Vol. 1. pp. 29-39.

Wells, R.E., J.G.W. Corns, D.T. Allan and J.R. Cuddeford, 1978. Biophysical land classification of Jasper National Park. Progress Report No. 3 (1977-1978). Canada Department of Environment, Northern Forest Research Centre, Edmonton, Alberta, unpublished. 428 pp.

Wishart, D.M., 1983. Revegetating a pipeline right-of-way on a montane grassland. M.Sc. thesis, Department of Forest Science, Univ. of Alberta, Edmonton, Alberta, unpublished. 224 pp.

Yamamoto, T., 1975. Coal mine spoil as a growing medium: Amax Belle Ayr South Mine, Gillette, Wyoming. In: Proceedings of third symposium on surface mining and reclamation, Louisville, Kentucky, October 21-23, 1975. National Coal Association, Washington, D.C. Vol. 1. pp. 49-59.

DEVELOPMENT OF A RECLAMATION TECHNOLOGY

FOR THE

FOOTHILLS/MOUNTAINS REGION OF ALBERTA

Terry M. Macyk, ALBERTA RESEARCH COUNCIL

ABSTRACT

Initiated in 1972, an on-going reclamation study has been conducted by the Soils Department of the Alberta Research Council on behalf of Smoky Coal Ltd. at their open-pit mine operations near Grande Cache, Alberta. The main objective of the project is to determine methods of establishing long-term cover that is in harmony with adjacent, undisturbed areas. During the study the unmined and reconstructed soils were characterized. Results of plot studies to determine the suitability and adaptability of various agronomic and native grasses and legumes suggest recommended species for use in the region. Methods for the establishment of trees and shrubs are presented. Encroachment by native species into the reclaimed areas and the use of these areas by wildlife are described. The results obtained to date from the research effort have been successfully transferred to the operational scale.

INTRODUCTION

The Alberta Research Council, Soils Department has been conducting a reclamation research program in the Grande cache area on behalf of, and funded by, Smoky River Coal (formerly Mc Intyre Mines Ltd.) since May, 1972. When the Alberta Research Council (ARC) undertook the project, reclamation research was truly in its infancy in Alberta. Techniques developed elsewhere, primarily in the United States, were not applicable to the Alberta situation. Furthermore, the issue of reclamation in Alberta was not formally addressed until the Land Surface Conservation and Reclamation Act of 1973 and the Coal Policy of 1976. This paper provides a summary of the work undertaken and an assessment of the results obtained. Results obtained thus far in this study provide a basis for a reclamation technology or the methodology for achieving reclamation success in the Foothills/ Mountains region. Details relating to the various aspects of the study are documented in the progress reports prepared annually (see reference list).

Setting

The operations of Smoky River Coal Ltd. are located approximately 13 km north of the town of Grande Cache in the Rocky Mountain Foothills. The two major surface mining operations are the No. 8 and No. 9 Mine areas located adjacent to the Smoky River and Sheep Creek respectively. Elevations range from 1600 to 1800 m and the topography is steeply sloping. Climate can be considered one of the major limiting factors to revegetation success. Frost and/or snow can and do occur in any month of the year and wind is a common phenomenon.

Objectives

The original objectives of the project were defined as follows. New ones were added as additional needs were identified.

1) Characterize unmined and reconstructed soils and evaluate their suitability for reclamation purposes;

2) Determine, by field testing, suitable grasses and legumes for establishment of a protective vegetation cover on reclaimed areas to minimize erosion;

3) Determine, by field and laboratory testing, the nutrient requirements for maintaining a viable vegetative cover;

4) Determine methods of establishing a long-term vegetative cover that is in harmony with adjacent, undisturbed areas.

MATERIALS AND METHODS

Coal production from the No. 8 Mine commenced in June, 1971. The research program that placed emphasis on soils and vegetation concerns began in May, 1972.

Pre-Mining Soils

A soil survey of that portion of the No. 8 Mine area that had not yet been disturbed by mining and the No. 9 Mine area indicated that the soils were dominantly Luvisolic and Brunisolic (CSSC 1978). The depth of salvageable material overlying bedrock ranged from less than 10 cm to in excess of 1 m with an overall average of approximately 50 cm. Analytical data indicated that these soils were moderately to slightly acid, medium textured and had low levels of available plant nutrients, especially nitrogen and phosphorus

Materials Handling Procedures

Soil salvage is an integral part of the materials handling program associated with the overall mining operation. Following the removal of merchantable timber, the soil overlying consolidated bedrock is removed in one lift in a manner such that a minimum amount of coarse fragments are incorporated. The soil materials are stockpiled for future use. Because the surface or organo-mineral horizons are minimal or nonexistent and the sola are quite variable in thickness, segregation or selective handling of soil materials is not considered.

Soil material is replaced on the spoil surface by scrapers or truck/caterpillar operations following the removal of overburden and coal and subsequent backfilling and grading. Scrapers tend to allow for a more uniform depth of soil replacement but they are limited by slope angle and they cause more severe compaction under moist conditions. Caterpillars are not as versatile as scrapers, however their tracks provide excellent seed germination sites.

Reconstructed (Post-Mining) Soils

The reconstructed soils that are developed do not duplicate the soils that existed prior to disturbance. The physical properties of the soils are the ones most drastically altered by the mining process. Soil structure is completely destroyed. Compaction by heavy equipment reduces pore space and makes the soils somewhat less pervious to water, roots and air. The silt loam texture combined with very low levels of organic matter results in a crusting problem which has a direct bearing on infiltration capacity and processes such as runoff and erosion. Infiltration tests indicated that the undisturbed or virgin soils had considerably higher infiltration rates than the reconstructed soils.

Overall, reconstructed soils are generally coarser textured, higher in pH and lower in available nutrients than unmined soils. These soils have some limitations, however, with proper management they are invaluable in achieving reclamation success.

Vegetation Studies

As was stated previously in the list of objectives the overall goal of the project was and is to establish long-term self sustaining cover that is in harmony with the adjacent undisturbed area. Erosion control was one of the initial considerations relative to establishment of a plant cover.

Therefore, a specific end land use(s) was not developed at the time the project was initiated. Instead, the idea was to first establish an erosion control cover and then get the area back to the original cover which suggested a forest cover not necessarily merchantable along with some capability for wildlife use.

The vegetation aspect of the study was initiated in May, 1972 with the establishment of three plot areas, the first of many to be utilized during the project term. The three locations involved 60 individual 6 x 9 m plots to determine the suitability of 30 different agronomic grasses and legumes. Slopes ranged from 0 to 40 degrees.

Fertilizer trials were included to determine the most appropriate fertilizer types and analyses to be used, as well as timing and rate of application.

A concern relative to utilization of native species was addressed early in the study. It had been suggested that native species be utilized because animals prefer them, that less maintenance is required after establishment and that natives are more aesthetically pleasing. Realistically however in 1972 there was very little "native" seed available. Consequently, seed from loco-weed (*Oxytropis* spp.), Alpine hedysarum (*Hedysarum alpinum*), lupine (*Lupinus* spp.) and Hairy wildrye (*Elymus innovatus*) was collected in the undisturbed portions of the mine area and subsequently cleaned and planted.

The native species issue was also approached from the standpoint of introducing trees and shrubs relative to meeting the objective of establishing a long term cover that is in harmony with the surrounding area. A major problem was encountered in that seedlings suitable for planting above an elevation of 1100 m were unavailable. Consequently, a cone collection program was undertaken and greenhouse space acquired to rear lodgepole pine (*Pinus contorta* var. *latifolia*), engelmann spruce (*Picea engelmannii*) and white spruce (*Picea glauca*). Different sizes and types of containers were utilized to determine those most suitable for use in reconstructed soils and to get an appreciation of the relative costs associated with seedling production.

Cuttings of willow (<u>Salix</u> spp.), balsam poplar (<u>Populus balsamifera</u>) and root cuttings of aspen (<u>Populus tremuloides</u>) were rooted in the greenhouse. Direct planting methods were also utilized for the cuttings of willow. Most of the materials produced were then planted within areas having an established grass and/or grass/legume cover.

During the 1983 growing season a limited amount of work was done with direct seeding of pine and spruce seed to determine whether this procedure might be useful to consider on an operational scale. A more extensive field program was undertaken during the 1984 growing season.

RESULTS AND DISCUSSION

Suitability of Agronomic Grasses and Legumes

Most of the agronomics that were planted initially, survived and continue to thrive. Many of the species produced and dropped viable seed. There was some concern at the outset that legumes, and in particular alfalfa, would not adapt or survive at the elevations involved in this study.

Time and annual monitoring of growth resulted in the development of an appreciation of species suitability (desirability), stand composition and fertilizer requirement. For example, with time and the withholding of fertilizers, alfalfa increased its share of the ground cover while the grasses, which tended to comprise a major portion of the initial cover in a mixed stand, declined in vigor. A number of recommended seed mixtures and seeding rates appropriate for different slope aspects (moisture regimes) were developed and are documented in the annual reports prepared (Macyk 1975, 1976, 1977). In terms of the most suitable time of year for planting, it was determined that spring seeding is superior to fall seeding for a number of reasons. The major reason is that legumes, which should be included in the cover established, perform much better when seeded in the spring.

To summarize, one might suggest that legumes such as alfalfa and clover along with the fescues, wheatgrasses, and wildryes are the most appropriate for revegetation use. Bromegrass and timothy provide good initial cover but tend to be highly competitive in mixtures and have relatively high nutrient requirements. Furthermore, the relatively large amounts of vegetative material produced by these species tends to support and promote the mouse population through late fall and winter.

Fertilizer Requirements

As indicated previously, the available nutrient levels of the undisturbed and reconstructed soils was quite low. The grasses and legumes showed a marked response to the application of fertilizers to the extent that fertilized plots produced 10 to 20 times more dry matter than the unfertilized plots.

A number of concerns surfaced relative to the use of fertilizers in reclamation. Firstly, there was the concern that large applications of fertilizer would be required annually to maintain the established cover. Furthermore, the original cover established was relatively dense which it was suggested would preclude invasion by natives and that resultant dead plant material would create a fire hazard in spring. The dead plant material probably does create a fire hazard but it is also useful from the standpoint of improving the organic matter status of the reconstructed soil.

On the basis of long term observations it can be stated that refertilization is not required annually to maintain a viable vegetative cover. Furthermore, a summary relative to timing of applications was developed and follows:

1) fertilizers should be applied at the time of seeding (year 1) and the following year (year 2);

2) for areas seeded to mixtures comprised of grass only, refertilization should take place in year 3 and every three years thereafter;

3) for areas where legumes such as alfalfa are included in the mixture, the vegetation cover can be left for five years and perhaps longer without refertilization.

Native Species Trials

Results indicated that the seed of some of the native grasses and legumes collected had relatively low germination rates. For example, the germination rate for loco-weed was 70 percent, whereas that of alpine hedysarum was 15 percent. It was observed that establishment of a viable erosion control cover utilizing natives only, took at least two years longer than when agronomics were used. Despite some of the limitations associated with utilizing natives, the species used in this study are considered appropriate for large scale use. A major concern relates to the acquisition of an adequate seed supply.

Relatively good success was achieved in terms of tree and shrub establishment. It was demonstrated that trees and shrubs will thrive in areas initially seeded to grasses and legumes. This practice was questioned initially because of an anticipated competition for moisture. It became apparent that the protection afforded the seedlings by the grass and legume cover, especially in holding snow in the winter, far outweighed the negative aspects of competition for moisture during the growing season.

Furthermore, it was noted that seedlings growing in association with alfalfa appeared more healthy and vigorous than those growing in association with grasses.

The following summary represents an assessment of results five years after the initial planting of trees and shrubs.

1) engelmann spruce survival rate - 65%
2) lodgepole pine survival rate - 50%
3) rooted willow and balsam cutting survival rate - 65%
4) direct planted willow cutting survival rate - 40%
5) container grown conifer seedlings are superior to bare root stock in terms of survival and growth rate
6) larger size containers promoted higher survival rates.

The issue of container vs bare root stock requires re-evaluation from the standpoint of growth rate.

Some problems were encountered relative to seedling mortality. Upon investigation of some of the seedlings that had expired, it became apparent that the upper root mass surrounded by the peat from the original container was exposed at the soil surface. This exposure is likely the result of frost heaving.

Direct seeding of spruce and pine seed has shown some promise, however assessment of the results of the 1984 field program will be required before any conclusions can be reached or recommendations made.

Recently, emphasis was placed on assessing some of the characteristics of trees planted in the reclaimed area and relating this to trees found in the adjacent forest and in areas reforested after harvesting operations.

In 1983, an assessment of the characteristics of trees planted in the reclaimed area relative to trees present in the adjacent forest was undertaken. Trees selected for examination or comparison were chosen on the basis of obtaining a similar species and sizes from both the natural and reclaimed areas. Trees were excavated to allow for examination of rooting habit and depth. Stem diameter at the base, age and height of each individual tree were determined.

Roots were concentrated in the upper 30 cm of the soil with only minor rooting below 50 cm for both spruce and pine within the reclaimed and undisturbed areas. Rooting habit or pattern was quite similar for trees excavated from the undisturbed and reclaimed areas.

The data obtained indicated that the growth rate for trees in the reclaimed area was considerably greater than that of trees growing in the natural forest. These results might be explained by the fact that the trees in the reclaimed setting may have benefitted to an extent from the fertilizers applied to the accompanying grass cover. Furthermore, the trees in the reclaimed area likely receive more direct sunlight than the trees in the natural forest setting. However, it should be pointed out that the trees in the reclaimed area are more exposed to climatic extremes such as wind.

In 1984, an attempt was made to compare the growth of trees in the reclaimed area with those growing in reforested areas that had previously been logged for pulp industry purposes. It was felt that this might provide a more valid comparison of growth since the reforested areas are more open to light etc. A site was selected approximately 40 km southeast of No. 8 Mine. The elevation of 1500 m is somewhat less than that of the mine but it was the highest or best that could be readily accessed. The data in Table 1 provide a comparison of results for the different locations.

Table 1 Age and Growth Data for Conifers

Treatment/Location	N*	Diameter (cm)	Height (cm)	Age (yrs)
Reclaimed-No. 8 Mine				
Spruce	12	1.4	55	11
Pine	12	2.6	75	11
Reforested				
Spruce	17	1.2	52	14
Pine	18	1.3	59	11
Natural Forest - No. 8 Mine				
Spruce	23	0.9	42	17
Pine	26	3.1	108	28

N* - number of trees

The data presented suggest that the trees growing in the reclaimed area are at least comparable to those in the reforested and the natural forest settings. It should also be noted that climate is more severe at the No. 8 Mine than at the location from which the reforested trees were obtained.

Encroachment by Natives

Field observations indicate that encroachment by natives into the disturbed areas will occur with time. Various lichens, mosses, lupine, loco-weed, alpine hedysarum and Indian paintbrush are naturally invading the areas initially seeded to agronomics. Willow, alder, balsam poplar and the conifers, dominantly spruce, pine and subalpine fir are also found in the area.

The encroachment by natives is the result of seed spreading from adjacent undisturbed areas and/or the result of incorporation of seed and vegetative material during soil salvage operations and the resultant germination of seed or sprouting of vegetative material following soil replacement.

These observations suggest that revegetation can be planned and managed in a manner such that natives can be included in the original seed mix and they can be expected to encroach or invade on their own. In other words, natives grasses, legumes, herbs, shrubs or trees will come in naturally if not planted originally. However the appropriate seeding or planting of natives speeds up the overall process.

Wildlife Utilization of Reclaimed Areas

During the initial stages of the study it was suggested that most wildlife species would not utilize reclaimed areas especially those where agronomic grasses and legumes were utilized. Bighorn sheep initially inhabited the experimental areas only in spring because the plots greened up earlier than their native range. Presently, they stay within the reclaimed area throughout the growing season, selectively grazing particular species such as alpine bluegrass, creeping foxtail, hard fescue and to some extent the tender shoots of alfalfa.

Transfer of Research Results to Operational Scale

The results of the experimental work were applied on a large scale early in the project; revegetation of major areas began in the fall of 1973, 16 months after the inception of experimental work. Seed mixtures and fertilizer applications were based on results available at that time and have been upgraded annually as more information became available. It was determined that hand broadcast of seed and fertilizer was more effective and had a higher cost-benefit than to hydroseeding and helicopter seeding. One troublesome aspect of going to the large scale involved that of incorporating the seed by roughening or scarifying the surface following the broadcast application. On a plot scale this was accomplished by hand raking, whereas for the large scale, several designs of a "drag" were prepared before one was built which was both suitable and adequately sturdy.

CONCLUSIONS

The results of the research project described suggest that reclamation in the Foothills/Mountains region of Alberta can be successful provided that certain techniques are utilized and specific procedures followed. The key requirements follow:

1) Soil salvage and replacement is practiced.

2) Appropriate agronomic grasses and legumes are selected to provide initial cover. Native species can be included in the mixtures.

3) Fertilization is practiced in a manner that allows for stand maintenance but also allows for desirable species competition and for encroachment by natives.

4) Appropriate seedling stock, cuttings, etc. are used for establishment of trees and shrubs. Some of the species will come in naturally but perhaps not in the density and certainly not as quickly as compared to plantings. More research is required to determine the merits of direct seeding of conifer seed to establish acceptable stands.

REFERENCES

Canada Soil Survey Committee, Subcommittee on Soil Classification, 1978. The Canadian System of Soil Classification, Canada Department of Agriculture Publication 1646. Supply and Services Canada, Ottawa, Ontario, 164 pp.

Macyk, T.M. and Widtman, Z.W., 1983. Progress report, surface mine reclamation project, No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 28 pp.

Macyk, T.M., 1982. Progress report, surface mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 18 pp.

Macyk, T.M., 1982. Progress report, surface mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 12 pp.

Macyk, T.M., 1981. Progress report, surface mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 21 pp.

Macyk, T.M., 1981. Progress report, surface mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 14 pp.

Macyk, T.M., 1980. Progress report, surface mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 26 pp.

Macyk, T.M., 1980. Progress report, surface mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 17 pp.

Macyk, T.M., 1979. Progress report, surface mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department Report, 21 pp.

Macyk, T.M., 1979. Progress report, surface mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Division Report, 31 pp.

Macyk, T.M., 1978. Progress report, surface mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Division Report, 36 pp.

Macyk, T.M., 1978. Progress report, surface mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Division Report, 22 pp.

Macyk, T.M., 1977. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Division Report, 41 pp.

Macyk, T.M., 1977. Progress report, strip mine reclamation project, No. 9 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Division Report, 20 pp.

Macyk, T.M., 1976. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. AIP Report M-76-11, 43 pp.

Macyk, T.M., 1976. Progress report, strip mine reclamation project, No. 9 Mine, Grande Cache, Alberta. AIP Report M-76-23, 18 pp.

Macyk, T.M., 1975. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. AIP Report M-75-9, 37 pp.

Macyk, T.M., 1974. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. AIP Report M-74-16, 39 pp.

Macyk, T.M., 1973. Progress report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta. AIP Report M-73-14, 35 pp.

Macyk, T.M., 1972. Interim report, strip mine reclamation project, No. 8 Mine, Grande Cache, Alberta, 20 pp.

PRELIMINARY REPORT

A STUDY OF THE NATURAL REVEGETATION OF PLACER MINING DISTURBANCES IN THE KLONDIKE AREA, YUKON TERRITORY.

Michael A. Brady and Dr. J.V. Thirgood

Faculty of Forestry, University of British Columbia, Vancouver, Canada.

A STUDY OF THE NATURAL REVEGETATION OF PLACER MINING DISTURBANCES IN THE KLONDIKE AREA, YUKON TERRITORY.

Michael A. Brady and Dr. J.V. Thirgood

Faculty of Forestry, University of British Columbia, Vancouver, Canada.

ABSTRACT

The purpose of this study is to identify and describe those spatial and temporal factors which influence successional trends of naturally revegetating mining disturbances. Vegetation communities ranging from 2 to 80 years in age are described on 67 sites disturbed by placer mining. Principal components analysis, a gradient analysis technique, is used to transform site environment variables into single component scores. Regression analysis is then used to isolate the determinants of vegetation patterns. The influence of site environmental conditions account for 48.8 % of the variation in total vegetation cover, 8.2 % of the variation is explained by site age, and 43.0 % by other residual factors. These residuals may include the influence of adjacent vegetated areas, soil movement as a result of erosion, climatic variability, sampling error, and chance. Once confounding effects of site age and residual factors are partitioned, vegetation cover and site conditions are significantly correllated. Soil moisture, soil macropore space and slope angle comprise the major environmental influences. This information is used to identify the condition present mine sites may be left in when abandoned, in order to promote optimal natural revegetation.

INTRODUCTION

Placer mining has taken place in the Klondike continously since 1896. Excavation of lower slopes and creek bottoms for mining purposes has resulted in extensive areas of disturbed land. Different mining techniques used in particular situations are reflected in the wide range of site conditions contained within these disturbed lands. In addition, despite the fact that mining equipment and methods have changed, site conditions produced today are similar to those produced by mining in the past.

To date, the mining industry has not been required to manage disturbed lands. Consequently, these areas have been left for nature to stabilize and revegetate. Current vegetation occuring on disturbed land represents a range of natural recolonization and establishment. Variation, in both the amount and type of vegetation on disturbed land in northern areas has been observed by Hernandez (1973), Hardy and Associates (1978), Naldrett (1982), Holmes (1982), and Durst (1982). Some mined lands support vegetation communities with characteristics similar to that of adjacent unmined areas, whereas other disturbances maintain vegetation quite distinct from that of the surrounding area.

Environmental features which have been disturbed by mining activity are also components of other environmental resources presently considered valuable by the people of Yukon and Canada (Fox, Eyre and Mair 1983 ,Placer Guidelines Review Committee 1983). Specifically, three types of resources or resource uses are being affected by mining: fishing, terrestrial wildlife, and recreation. In order to maintain features of the environment in a condition such that these other resource values may be realized, mined-land management is necessary. Revegetation of surface-mined land is perhaps one of the most critical components of any land management procedure (Banks, Nickel, and Blome 1981). In this respect vegetation helps:

1) Stabilize soil, thus slowing erosion and sediment discharge.

2) Enhance wildlife habitat, and

3) Improve the aesthetic quality of a site, thus making it more attractive for recreation.

This study is concerned with identifying and describing spatial and temporal factors which may influence the successional trends of naturally revegetating mining disturbances. It will concentrate on describing the nature of present regrowth in the Klondike, and provide an assessment of factors which may have led to its present composition and distribution. Specifically, the study will determine the extent to which total vegetation cover, along a successional gradient, is determined by site characteristics.

The analysis and results presented in this preliminary report address relationships between vegetation cover and environmental factors of mined land. The amount of vegetation cover on disturbed land is generally considered to be a measure of the ability of that land to resist soil erosion (Rutter 1967). Cover reduces the impact of rainfall on soil, increases adsorption, checks the speed of flowing water, and binds the soil (Agric. Canada 1961).

The results of this study will aid in the prediction of natural revegetation patterns on present day disturbances. In addition, an understanding of conditions amenable to natural revegetation will aid in determining the extent to which revegetation management is required in order that other resource values may be recognized. This report will suggest environmental management practices which involve the use of ecological information pertaining to the sensitivity and/or the resiliency of a disturbed ecosystem. This form of environmental management has been recognized by others (Hollings 1978, Beanlands 1983).

Revegetation characteristics of individual species are discussed in a Masters thesis by Brady (1984).

LITERATURE REVIEW

Considerable research has been completed in the field of applied mined-land revegetation in the North (Johnson and VanCleve 1976; Peterson and Peterson 1977). However, few studies are concerned with the natural revegetation of lands disturbed by mining. Errington (1975) and Meidinger (1979) in British Columbia, and Hernandez (1973) in the Northwest Territories, have studied natural revegetation on abandoned roads and mining disturbances. Hardy Associates (1980) in Yukon, and Rutherford and Meyer (1981), Durst (1981) and Holmes (1982) in Alaska, recently completed studies about natural revegetation on dredge tailings and associated disturbances. These studies are generally descriptive in nature. The variation in vegetation composition and abundance (percent cover) between the disturbed sites was not related to the combined effects of;

1) Site conditions (slope, texture, etc.),

2) Site age (revegetation period), and

3) Unexplained or residual factors (chance, seed source, climate, etc.).

An understanding of the proportion of influence that each of these factors may have on disturbed land will aid in the identification of optimal conditions for revegetation of present-day mining sites. Specifically, the degree of manipulation of site factors, such as slope angle, material compaction, percentage of fine material, and water supply which will promote vegetation, can be quantified.

STUDY AREA

The study area is located within the Klondike Plateau portion of the Western Yukon Plateau (Bostock 1948). This region is characterized by narrow, deeply disected "V" shaped valleys often associated with unglaciated terrain. The plateau is developed mainly on Paleozoic metamorphic rocks with extensive areas of Tertiary age basalts, shales and sandstones. Some valleys contain high level gravel benches over bedrock terraces and varying depths of creek gravels over the valley floors (McConnel 1906). Most of the area lies below 1000 m in elevation and the study sites range between 400-600 m above sea level. The disturbed areas are located within the Bonanza, Klondike, Hunker, Sulphur and Gold Run drainage basins, on alluvial plains and terraces.

The climate of the Klondike is subarctic continental, characterized by long cold winters and short hot summers. Mean annual temperature is -5 C, with extremes of -28 C in January and 15 C in July (Environment Canada 1982). Temperatures are extreme, and frost may occur in any month. The average frost-free period is 92 days with 910 degree-days over 9 C (1941-70). Mean annual precipitation ranges from 306 to 350 mm over much of the low elevation terrain which includes the mined areas of interest. Average rainfall between June and August is 141 mm, with maximum rainfall occuring in late summer (Env. Can. 1982).

The study area lies within the discontinuous permafrost zone. In general, vegetated valley flats and north facing slopes have permafrost. Frozen ground is usually lacking on south facing slopes, under valley floors of large streams, and in recent alluvium. Most mining activity has occured in permafrost areas.

The Klondike Plateau is covered by Boreal forest . Commonly, lower slopes contain black spruce (Picea mariana) and white spruce (Picea glauca) in pure stands or mixed with aspen (Populus tremuloides), balsam poplar (Populus balsamifera), and paper birch (Betula papyrifera ssp. Humils). In areas of permafrost and/or poor drainage the primary association consists of black spruce, with a shrub layer of labrador tea (Ledum palustre), and a thick mat of feather moss, sphagnum and lichen. Willows (Salix sp.) and ericaceous shrubs are commonly abundant in the understory on most sites. Within the Klondike , it is important to note that during the extensive mining activities of the early 1900's, nearly all the forests were cut for lumber and fuel. The present vegetation is a result of regrowth from that period.

FIELD METHODS

Soil, vegetation, and site conditions were examined at 67 sites disturbed by mining activity between 1898 and 1981. Field work was completed during the summer of 1983. Sites were located within the lower slopes and valley bottoms of the heavily disturbed drainages near Dawson City, Yukon territory. They were selected to illustrate a range of revegetation occuring over a wide variety of environmental conditions and age since disturbance. The locations and ages of mining areas sampled were identified by utilizing four sources of information. These included the Dawson Mining Recorder ledgers, Yukon Archives, various local publications and a heavy reliance on information provided by a few of the more experienced miners in the area. The estimated age since disturbance on sites older than 40 years since abandonment, is considered to be accurate to within five years.

Sample areas within the disturbed sites were selected to represent the dominant revegetation pattern occuring over the largest portion of the site. Approximately ten sample points were randomly located within each sample area. Vegetation and soil information was then recorded. Estimates of total vegetation cover, tree density and dominance, cover by species and strata, surface stoniness, litter cover, and exposed bare areas are examples of data collected at each site. The largest trees in the sample areas were identified and increment cores taken for age determination. In addition, observations were made on the vigour of the major recolonizing species and comments were recorded about microtopographical influence and species propogation. A brief description was also made of vegetation on adjacent unmined areas.

Estimates of soil texture and percentage by volume of fine material (< 2 mm diam.), coarse material (> 2 mm diam.) and macropore space were visually estimated from 10 small (15 cm in depth) pits which were dug at each site. A major soil pit (up to 1 m in depth) was excavated at a point determined to be representative of the general soil condition of each sample area. The soil profile was described and comments pertaining to soil development were recorded. Material samples from the top 15 cm of three of the small pits were taken for physical and chemical analysis. A detailed description was then made of site conditions. Slope angle and configuration, aspect, topographic position, parent materials and modifying processes (washed gravel) were recorded for each sample area.

RESULTS AND DISCUSSION

Soil drainage, % fine material, macropore void space, and slope angle are environmental variables which best explain the conditions of each of the 67 sample areas. Figure 1 illustrates the scalar ranges of these environmental variables.

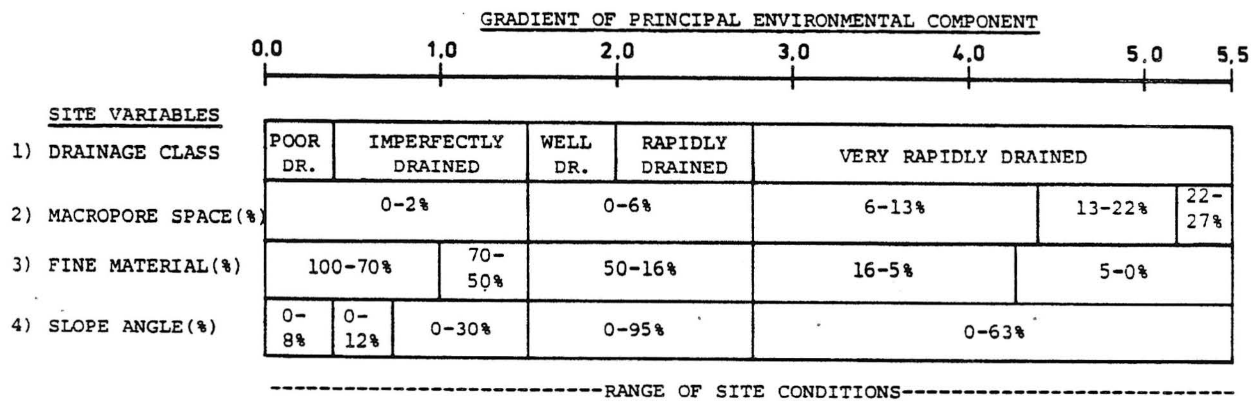


Figure 1. Scalar ranges of four environmental variables representing the site environmental gradient.

The Environmental gradient presented in figure 1 summarizes major trends in substrate composition and moisture supply. Gradient boundaries were identified using an ordination technique refered to as Principal Components Analysis (Pimentel 1979). The upper half of the gradient (92.8 - 5.50) represents very well drained soil conditions, characterized by a range of 0 - 16 % fine material, 0 - 63 % slope angles and 8 - 27 % soil macropore space. Soils in this drainage class have very low available water storage capacity (usually less than 2.5 cm) within the control section, and are usually coarse textured, or shallow, or both (CanSIS 1982). Water source is primarily precipitation. The lowest portion of the gradient (0.0 - 2.5), classed as poorly drained, is characterized by ranges of 70 - 100 % fine soil material, 0 - 8 % slope angles and 0 - 2 % soil macropore spaces. Water is removed from the soil sufficiently slowly, in relation to supply, such that the soil remains moist for a significant part of the growing season (CanSIS 1982).

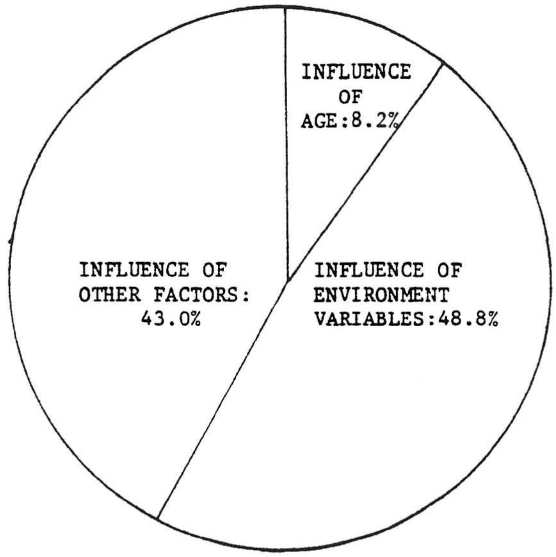
Subsurface flow or groundwater flow, or both, in addition to precipitation, are the main water sources in poorly drained areas. These soils may exhibit a wide range of available water supply, texture and depth. Thus, the wide range of some of the scalar values (eg. 0 - 63 % slope angles) may be a result of variability in water supply to each sample area.

Partitioning Determinants of Vegetative Cover

Linear regression analysis was performed using total vascular cover values, against age since disturbance of each sample area. The regression coefficient indicates that 8.2 % of the total variation in vegetation cover is due to the influence of site age. This low correlation appears reasonable, considering the variability between sample areas. For example, several mined areas, abandoned two years previous to the study (1981), contain up to 80 % vegetation cover. Conversely, some areas dredged up to 70 years ago were observed to have less than 5 % ground cover. The small variation related to site age, may partially be explained by the extremely wide range of man made conditions produced by mining activity. For example, settling ponds often contain 100 % fine material (silt loam), whereas dredge tailings may contain no fine material and up to 27 % macropore void-space. Ninety one percent of the variation in vegetation cover is accounted for by factors other than age of site. Thus, site conditions and adjacent vegetated areas have a much greater influence on vegetation growth than does the time period since abandonment.

A second regression was performed to further partition the determinants of vegetation cover into effects due to site conditions and those due to unmeasured residual variables on and off the site. The second regression line, representing the influence of site conditions, accounts for 48.8 % of the variation in vegetation abundance. The remaining 43 % of variation represents the influence of all factors affecting vegetation growth that were not measured at each sample area. As such, it represents that portion of the data that remains unexplained following the identification of the influence of site condition and age. Figure 2 illustrates the proportion of influence of each of the three determinants on vegetation cover over the disturbed sites.

Figure 2. The proportion of influence of spatial and temporal factors on vegetation abundance is partitioned into: 1) site age, 2) site conditions, 3) unidentified residual factors.



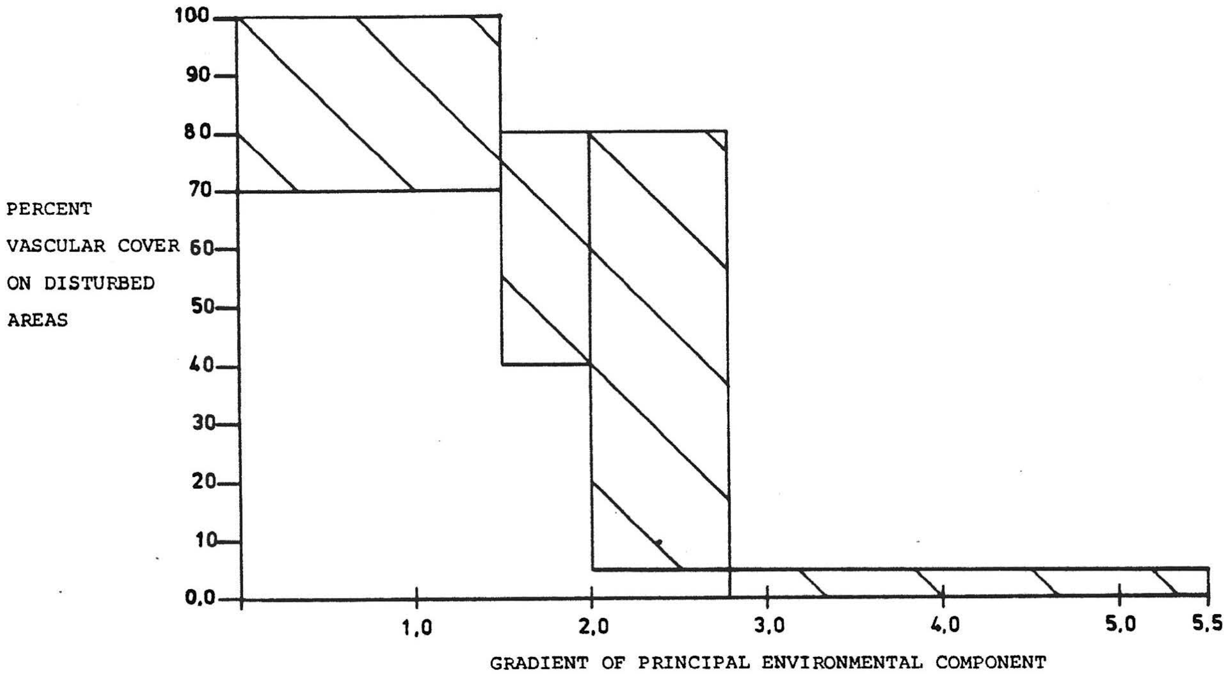
Residual factors may represent variables such as climate, soil nutrients, sampling error, and the effects of soil erosion. In general, soil movement may inhibit plant propogation. However, due to low rainfall in the Klondike (320 mm/year) and the coarse textured soils exposed by mining, little evidence of erosion was observed on uphill sites, except where degrading permafrost provides a continual source of water. However, considerable bank erosion was observed in valley bottoms where stream levels fluctuate continually. The resultant unstable substrate conditions do not provide a medium for revegetation .

In addition to on-site conditions, the influence of adjacent vegetated areas surrounding the disturbances must be considered. These areas provide a source of seed for the revegetating sites. However, there is some variability in the capacity of adjacent areas to provide both quality and quantity of seed. Wind direction, tree age and seed production, dispersal periods of seed, and dispersal distance are factors influencing seed availability from adjacent areas to disturbed sites (Zasada 1971). They require consideration when assessing the revegetation potential of any site.

Although aspects of seed source availability are factors to be considered, it is important to note that as a result of the frequent fire regime and extreme seasonal temperatures characteristic to the North, many plant species have developded wide tolerance ranges to environmental conditions and in general, are capable of rapid recolonization in many disturbed areas (Viereck, 1983). Preliminary field observations indicate that the influence of adjacent vegetated areas are most prominent on mesic-type sites and mainly evident in understory species composition. Most tree species were found in any site condition, and their cover and density values did not appear to be affected by the proximity of adjacent stands.

Vegetation - Environment Relationships

Figure 3 illustrates the relationship between vegetation cover and environmental conditions of mined land in the Klondike. The influences of both site age and unidentified residual factors (adjacent vegetated areas, soil nutrients, climate, etc.) have been removed so as not to confound this relationship.



SITE VARIABLES

Site variable							
1) DRAINAGE CLASS	POOR DR.	IMPERFECTLY DRAINED	WELL DR.	RAPIDLY DRAINED	VERY RAPIDLY DRAINED		
2) MACROPORE SPACE(%)	0-2%	0-6%	6-13%	13-22%	22-27%		
3) FINE MATERIAL(%)	100-70%	70-50%	50-16%	16-5%	5-0%		
4) SLOPE ANGLE(%)	0-8%	0-12%	0-30%	0-95%	0-63%		

---------------------------RANGE OF SITE CONDITIONS---------------------------

Figure 3. A graph illustrating the relationship between vegetation cover and the range of site conditions (gradient of principal environmental variables) found on land distubed by mining in the Klondike. Hatched areas represent the range of both vegetation cover and site conditions.

The ranges of vegetation cover associated with portions of the site condition gradient illustrate the variation in vegetation response to the mined sites. For example, comparatively narrow ranges of cover values are found at the extremes of the gradient, while wider ranges occur in the central portion. This suggests that vegetation response is more predictable at extremes of the gradient of site conditions.

70-100 % cover values are most often found in moist areas which are characterized by substrate conditions of; poor drainage, 0-2 % macropore space, 70-100 % fine material and slope angles of less than 8 %. Conversely, 0-5 % cover values are found in dry areas characterized by; very rapidly drained substrate conditions with 6-27 % macropore space, 0-16 % fine material and slope angles of up to 63 %. Medium sites however, contain a wider range of site conditions, and vegetation response is highly variable. It is within these intermediate areas where adjacent vegetated areas may have the most influence on vegetative composition. Interactions between colonizing plant species become increasingly complex as site age increases. Eventually, vegetation begins to modify the site, producing a more favorable medium for growth.

Very dry sites support few plant species. These include; lichens (Cladina , Stereocaulon), mosses (Polytrichum), small shrubs (Rubus , Salix), and trees (Betula , Populus). The degree to which these species may alter their environment is limited. Similarly, moist sites support a limited number of species. These include plants capable of rapid colonization and growth. Willows (Salix sp.), alders (Alnus sp.), grasses (Calamagrostis sp.) and horsetails (Equisetum sp.) are commonly found in wetter areas. Detailed species - environment descriptions are provided in a report by Brady (1984).

SUMMARY

Substrate conditions of the disturbed sites are best characterized by differences in; soil drainage, the volume of soil macropore space, and slope angle. These variables reflect a gradient of both soil water holding capacity, and moisture supply. The influence of site conditions accounts for 48.8 % of the variation in vegetation cover on the mined sites. Another 8.2 % of this variation is a function of site age, and 43.0 % is accounted for by other unmeasured factors. These may include; 1) the ability of the adjacent vegetated areas to supply viable seed, 2) the stability of substrate material as a result of wind or water erosion, 3) the chemical composition of the substrate, 4) climate, and 5) chance.

Revegetation trends appear to be more predictable at the extremes of the gradient representing mined site conditions (figure 3). With site age partitioned, 70-100 % vegetative cover was found over moist sites and 0-5 % cover over the driest sites. Intermediate sites were observed to exhibit a wide range of cover values; between 5 and 80 %.

The study area includes all major streams in the Klondike, extending south to the Indian River. Observations were also made in the Clear Creek area east of Dawson. Revegetation conditions here appeared similar to those found in the Klondike. However, further east towards Mayo, an increase in precipitation rates may alter the natural revegetation potential from that of the Klondike. Further observations are required to determine the geographical extent to which the results of this study may be extrapolated.

MANAGEMENT INTERPRETATIONS

Based on the information derived from the preceeding analysis, the following management considerations are suggested. These refer to the conditions which present mining operations should be left in, to promote optimal natural revegetation.

A) SITE AGE CONSIDERATIONS

1) Site age has little influence on the amount of vegetation on disturbed land in the Klondike. However, older sites with little vegetative cover are generally coarse textured. They do not appear to contribute to soil loss and water quality problems. Revegetation of these coarse textured sites will require specific treatment to meet desired land-use goals.

B) SITE CONDITION CONSIDERATIONS

1) Improvement in substrate moisture holding capacity may increase the revegetation potential of placer mined land. This can be accomplished by compacting coarse material, reducing macropore void-space to 5 % , preferably lower. Also, slope surfaces should be kept to a minimum angle, preferably less than 30 %, and fine material content (% fine sand, silt and clay) should be 50 %, or greater.

2) Revegetation of disturbed land is also dependent upon the amount of moisture supplied by precipitation, or more importantly (due to low rainfall rates), subsurface seepage and groundwater. Improved moisture supply may be promoted by controlled flooding of coarse textured material in valley bottoms. This procedure promotes siltation and accumulation of fine material, which will improve substrate moisture holding capacity. In addition, mounds of coarse material may be levelled and recontoured to reduce the depth to water supply for plant roots.

C) OTHER CONSIDERATIONS

1) Generally, adjacent vegetated areas are capable of providing seed to mined land in the Klondike. Thus, active seeding and fertilizing programs are not necessarily required for revegetation of these areas. This study has illustrated that mined land can be abandoned in conditions that promote high levels of natural revegetation. This degree of vegetation resiliency is unique to northern areas and cannot be related to that of southern Canada. It is believed that the increse in fire frequency associated with northern areas is the reason for this phenomenon. Carleton and Maycock (1978), in a study on the effects of fire, observed that deforested sites in northern regions become reforested more rapidly and extensively than than those in southern forest regions. Shafi and Yarranton (1973) suggest that evolutionary pressures in a repeatedly disturbed environment have resulted in species adapted for rapid growth and reproduction. Considering these differences in natural revegetation potential, vegetation management of mined land in the Klondike should not necessarily be based on criteria used for southern mining situations.

2) Soil movement may reduce revegetation potential of disturbed sites. Two types of soil instability problems were observed to inhibit plant propagation and growth:

I) Degrading permafrost in excavations can provide excessive moisture on slopes, and promote sliding of soil material. Where permanetly frozen ground has been disturbed, slope angles should be reduced to enable moisture to penetrate the surface. Adequate drainage pathways may also be required to drain water from the thawed material.

II) Fluctuating stream levels appear to contribute to instability problems in valley bottoms where spoil material has not been recontoured and sufficient channel stabilization established. Stream bank erosion often inhibits vegetation establishment and may contribute sediment to the stream. In contrast, on uphill sites sheet and gully erosion does not appear to cause significant substrate instability problems. Low precipitation rates, in combination with the well drained alluvial material associated with the mining areas little surface overland flow of water.

ACKNOWLEDGEMENTS

I would like to acknowledge the following people: R.J.Cathro for providing the initial impetus and encouragement for this study. A.C.Ogilvey for organizing the financial assistance with D.I.A.N.D. Dr. J.V.Thirgood for his reclamation experience. Dr. L.Larson for providing a practical background in developing the experimental design of the study. S.Caditz for spending many long hours in the field completing the soils work. Special thanks to Dr. J.Maze and R.Scagel for their helpful discussions and advice on the data analysis. I am also grateful to the many miners in the Dawson area, to numerous to mention, who helped me locate and date most of the old mine sites.

REFERENCES

Agriculture Canada 1961. Soil Erosion By Water. 35 pp.

Bostock, H.S. 1948. Physiography of the Canadian Cordillera with Special Reference to the Area North of the 55th Parallel. Memoir 247. Geological Survey of Canada. Ottawa.

Beanlands, G.E. And P.N. Duinker. 1983. An Ecological Framework For Environmental Impact Assessment In Canada. Institute For Resource and Environmental Studies. Dalhousie University. Halifax, Nova Scotia . 132 pp.

Brady, M.A. 1984. A Study of the Natural Revegetation of Placer Mining Disturbances in the Klondike Area, Yukon Territory. M.Sc. Thesis. Faculty of Forestry, University of British Columbia. Vancouver, Canada.

CanSIS. 1982. Canadian Soil Information System. Manual for Describing Soils in the Field. Land Resource Research Institute, Research Branch, Agriculture Canada.

Carleton, T.J. 1984. Residual Ordination Analysis: A Method for Exploring Vegetation-Environment Relationships. Ecology 65(2), 469-477 .

Carleton, T.J. And P.F. Maycock. 1978. Dynamics of Boreal Forest South of James Bay. Can. J. Bot. Vol. 56: 1157-1173.

Durst, J.D. 1981. Vegetation Responses to Gold Dredging At Nyac, Alaska, With Wildlife Implications: A Progress Report. Bureau of Land Management, Anchorage District Office. Anchorage, Alaska.

Environment Canada. 1982. Canadian Climate Normals-Temperature and Precipitation-The North, Y.T. And N.W.T. Environment Canada. Ottawa.

Errington, J.C. Errington, J.C. 1975. Natural Revegetation of Disturbed Sites. Ph.D. Thesis. University of British Columbia, Vancouver, Canada.

Fox, I.K., P.J. Eyre, and W. Mair. 1983. Yukon Water Resources Management Policy and Institutional Issues. Westwater Research Centre. University of British Columbia. Canada. 52 pp.

Hardy Associates (1978) Ltd. 1980. Fish and Wildlife Habitat Recovery in Placer Mined Areas of the Yukon Territory.(Unpublished). Dept. Of Indian and Northern Affairs. Yukon Territory.

Hernandez, H. 1973. Natural Plant Recolonization of Surficial Disturbances, Tuktoyaktuk Peninsula Region, N.W.T. Can. J. Bot. Vol. 51: 2177-2196.

Hollings, C.S. (ed.). 1978. Adaptive Environmental Assessment and Management. International Institute for Applied Systems Analysis. Wiley and Sons. New York. 377 pp.

Holmes, K.W. 1982. Natural Revegetation of Gold Dredge Tailings at Fox, Alaska. M.Sc. Thesis (Unpublished), University of Alaska, Fairbanks, Alaska. 172 pp.

International Society of Soil Science (I.S.S.S.). 1978. Guidebook for a Tour of Soil, Permafrost and Vegetation Relationships in the Yukon and Northwest Territories of Northwestern Canada. Tour 18, pp. 1-65.

Jasieniuk, M.A. And E.A.Johnson. 1982. Peatland Vegetation Orginization and Dynamics in the Western Subarctic, Northwest Territories, Canada. Can J. Bot. Vol. 60: 2581-2593.

Johnson, E.A. 1981. Vegetation Orginization and Dynamics of Lichen Woodland Communities in the Northwest Territories, Canada. Ecology Vol. 62(1): 200-215.

Johnson, L. And K. VanCleve. 1976. Revegetation in Arctic and Subarctic North America: A Literature Review. U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). Report 76-15. 32 pp.

Kojima, S. 1972. Phytogeocoenoses in the North Klondike River Valley, Yukon Territory. 1972 Progress Report. N.R.C. Grant A-92.

Larsen, J.A. 1980. The Boreal Ecosystem. Academic Press. New York. 500 pp.

Larson, L. 1980. A Survey of Techniques for Measurement of Herbaceous and Shrub Production, Cover and Diversity on Coal Lands in the West. Office of Surface Mining, Region Five, Dept. Of Interior. U.S.A.

McConnel, R.G. 1906. Officers Reports-Klondike District, Yukon Territory. Geological Survey of Canada Annual Report. Vol. 15: 5B-71B

Meidinger, D.V. 1979. Natural Revegetation of Disturbances in the Peace River Coalfields. M.Sc. Thesis. University of Victoria, Victoria, Canada.

Meuller-Dombois, D. And H. Ellenburg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons. New York. 475 pp.

Naldrett, D.N. 1982. Aspects of the Surficial Geology and Permafrost Conditions, Klondike Goldfields and Dawson City, Yukon territory. M.Sc. Thesis. University of Ottawa. 150 pp.

Orloci, L. 1973. Ranking Characters by a Dispersion Criterion. Nature 244: 371-373.

Orloci, L. 1975. Measurement of Redundancy in Species Collections. Vegetatio 31: 65-67.

Peterson, E.B. And N.M. Peterson. 1977. Revegetation Information Applicable to Mining Sites in Northern Canada. Environmental Studies No. 3. Indian and Northern Affairs. Ottawa. 405 pp.

Pimentel, R.A. 1979. Morphometrics. The Multivariate Analysis of Biological Data. Kendall/Hunt Publishing Co. Dubuque. 276 pp.

Placer Guidelines Review Committee. 1983. Resources, Regulations and Reality. Placer Guidelines Review Committee. Ione Christensen - Chairperson. Whitehorse, Yukon. 147 pp.

Rutherford, C. And K. Meyer. 1981. Revegetation on Gold Dredge Tailings, NYAC, Alaska. (Unpublished Report) Bureau of Land Management, Anchorage District Office. Anchorage, Alaska. 51 pp.

Rutter, N.W. 1967. A Method for Predicting Soil Erosion in the Rocky Mountain Reserve, Canada. Geological Survey of Canada. Report 67-67. 31 pp.

Shafi, M.I. And G.A. Yarranton. 1973. Diversity, Floristic Richness, and Species Evenness During A Secondary (Postfire) Succession. Ecology Vol. 54: 897-902.

Tempelman-Kluit, D.J. 1980. Evolution of Physiography and Drainage in Southern Yukon. Can. J. Earth Sciences Vol. 17(9): 1189-1203.

Viereck, L.A. 1983. The Effects of Fire in Black Spruce Ecosystems of Alaska and Northwestern Canada. In: The role of Fire in Northwestern Circumpolar Ecosystems, chapter 11. Ed. R.W. Wein and D.A. MacLean. Wiley and Sons. Pp. 201-220.

Zasada, J.C. 1971. Natural Regeneration of Interior Alaska Forests; Seed, Seedbed, and Vegetative Reproduction Considerations. In: Proceedings - Fire in the Northern Evironment. College, Alaska.

LANDSLIDE REFORESTATION AND EROSION CONTROL IN THE QUEEN CHARLOTTE ISLANDS, B.C.

William J. Beese, MacMillan Bloedel Limited, Nanaimo, B.C.

Abstract

Control of sedimentation in anadromous fish bearing waters from surface erosion of landslides, and reforestation of large debris slide tracks, are two major concerns of land managers in the mountainous, high rainfall forest lands of the Queen Charlotte Islands. Results of the initial phases of a project designed to test several methods of landslide rehabilitation are presented. Helicopter hydroseeding of grasses, legumes and fertilizer, followed by planting of several native shrub species and container-grown tree seedlings in several combinations and planting designs, are being tested as methods for controlling surface erosion and establishing a forest crop. Linear versus grid shrub planting designs, and development of stabilizing root networks by various species, are being tested with regard to their effect upon tree growth. Trials will be monitored for five years. Previous erosion control activities in the Queen Charlottes are also reviewed.

INTRODUCTION

Forest harvesting and roadbuilding activities in steep, mountainous terrain can cause an increase in soil mass movements, particularly in high rainfall areas of coastal British Columbia. Large debris slides or avalanches on productive forest land are of concern for at least two reasons: 1) soil loss through erosion and subsequent sedimentation in streams, and 2) temporary or permanent loss of sites from the productive forest land base. Studies have also quantified a decline in productivity compared to logged sites of the same age due to loss of soil material (Miles et al. 1984, Smith et al. 1984).

This project investigates the use of bioengineering techniques for artificially accelerating natural succession on landslides. Hydroseeding -- applying seed in a water slurry that usually contains fertilizer and a tactifier or mulching agent -- is an effective way to check surface erosion on steep slopes. Combining shrubs with grass-legume cover will provide a better stabilizing root network than grass-legume cover alone. The value of shrubs in slope stabilization methods is well-documented (Schiechtl 1980). Questions as to the positive or negative effects (e.g., shading, competition) of shrub plantings on conifer establishment, and whether planting designs or shrub species differ in these effects remain to be answered.

OBJECTIVES

The objective of this project is to evaluate methods for early reestablishment of conifers on debris slide tracks. Specifically,

- to compare conifer plantation success when combined with hydroseeding alone versus hydroseeding plus shrub planting;
- to evaluate the effect of shrub planting design (row vs. grid) on conifer establishment;
- to test the suitability of several shrub species for mixed conifer/shrub plantings.

In addition, further testing of an aerial hydroseeding technique designed for revegetating steep landslides that are inaccessible to conventional truck-mounted hydroseeders will be done.

METHODS

Study Area

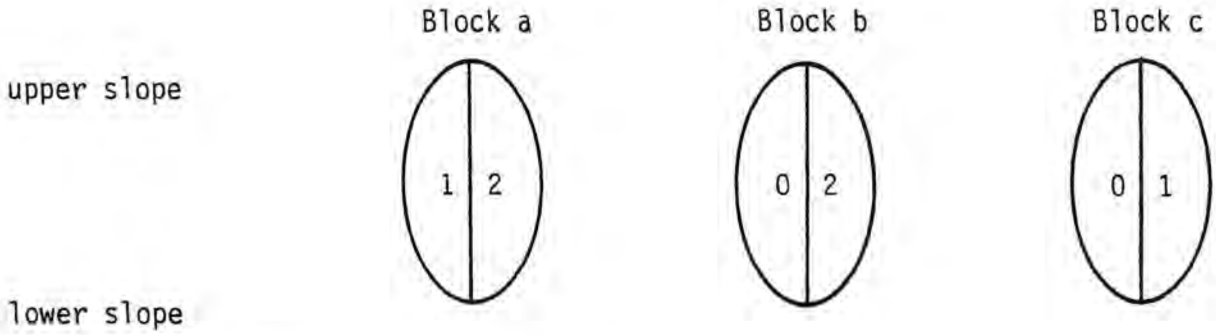
The Queen Charlotte Islands lie off the north coast of the B.C. mainland. The study area is a 2 ha slide near Sue Lake, about 20 km north of Queen Charlotte City. The slide occurred 10 years ago as a road-induced failure resulting from an overloaded fill slope. Since the initial slide, its size has increased and only small islands of vegetation have become established. There is over a meter of glacial till on most of the slide. Some portions have a surface layer of angular, gravel-sized rock fragments (colluvium) over the till.

Experimental Design

I set up the project as two separate trials: planting design and shrub species performance. The planting design trial tests conifer plantation success with grid versus row plantings of the same shrub species. I used a randomized incomplete block design, in which two replicates each of the two treatments and a control (no shrubs) were allocated randomly to three portions of the slide (blocks) that were divided vertically in half (Figure 1). Two year old sitka alder (Alnus sinuata), grown as plugs and transplanted, were planted either in a 1 x 1 m grid spacing or in rows 4 m apart with plants every 25 cm within rows. Both planting patterns give the same density.

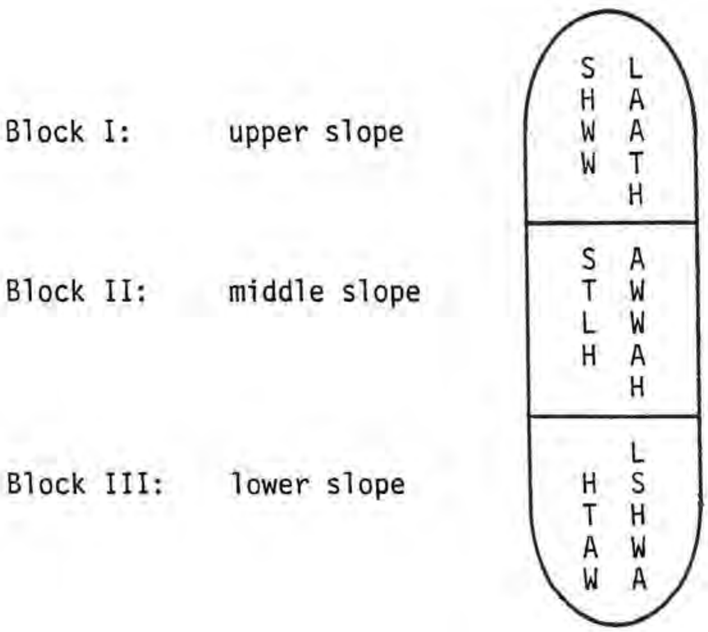
The shrub species performance trial tests the suitability of six native shrub species for mixed plantings with conifers. I used a randomized complete block design, in which two replicates of 50 plants of each species were allocated randomly within each of three portions of the slide (blocks) representing the upper, middle and lower slope positions (Figure 2). The shrub species being tested are: sitka alder, willow (Salix spp.), hardhack (Spirea douglasii), thimbleberry (Rubus parviflorus), salmonberry (Rubus spectabilis) and honeysuckle (Lonicera involucrata). As part of this trial, 40-60 shrubs of each species were planted on a roadcut near the slide. Ten plants of each species will be excavated each fall to observe and measure root system development.

Figure 1. Experimental layout for planting design.



0 = control - hydroseeding only
1 = treatment 1 - hydroseeding plus shrubs in grid
2 = treatment 2 - hydroseeding plus shrubs in rows

Figure 2. Experimental layout for shrub performance.



Shrub species:
A - alder
H - Hardhack
L - Honeysuckle
S - Salmonberry
T - Thimbleberry
W - Willow

Each letter in the diagram represents 50 plants in a 5 x 10 m plot.

Both the planting design and shrub species performance trials were hydroseeded with a grass-legume mixture and planted with sitka spruce (Picea sitchensis) 1+0 PSB 211 stock at 2 x 2 m spacing (2500/ha). A higher density than normally used in reforestation was chosen to allow for anticipated seedling mortality.

Sampling Procedures

The trials will be monitored annually for five years. Success will be measured in terms of seedling growth and survival on permanent sample plots. Twenty 1 m^2 plots will be established within each treatment unit to measure percent coverage and survival of the grasses and legumes, and percent bare mineral soil. A total of 150 trees will be measured for each treatment in both trials, 25 trees in each of the two replicates (5 rows of 5 trees) in the upper, middle and lower segments of the slope. Percent survival, height growth (cm), vigor, deer browse evidence and shrub competition will be observed. Shrubs will be measured using the same system as the conifers. For the 10 plants of each species examined annually, rooting depth and root zone diameter will be measured (as far as possible) along with average foliage crown diameter. Five root systems of each species will be collected, washed, oven dried and weighed at year 1, 3 and 5 of the sampling period as a comparison of root biomass.

Erosion Measurement

Twelve erosion measurement stations were established on the Sue Lake slide to monitor surface erosion over the first 5 years of vegetation establishment. The erosion bridge technique (Ranger and Frank 1978, Blaney and Warrington 1983) was used. This simple procedure consists of driving three lengths of steel reinforcement bar approximately 1.2 m apart in a line perpendicular to the slope, levelling the tops of the three bars, and measuring the distance between the ground surface and a modified masonry level placed on the bars. One station was installed in the upper, middle and lower portions of the slide in each of the three shrub/hydroseeding treatment areas. An additional three stations were placed in an unseeded portion of the slide as a control.

Data Analysis

Analysis of variance will be performed to determine if there are significant differences between the means for percent survival, height growth, browse, surface erosion, shrub competition, and percent of seedlings affected by slope disturbance for the various combinations of treatments. Subsequent to analysis of variance, students t-tests will be performed on the means.

REVIEW OF PREVIOUS WORK

This project is an extension of work begun in the Queen Charlotte Islands in 1980 by Carr and Marchant and reported at the Canadian Land Reclamation Association (CLRA) Annual Meeting in 1981 at Cranbrook, B.C. Several landslides were hydroseeded with grasses and legumes, and planted with several native shrub species. This work concentrated on erosion control and soil stabilization without specific regard to conifer establishment on landslides. It also focused on propagation techniques for numerous shrub species. I visited these earlier trials with Bill Carr in the Fall of 1983 to evaluate their performance. We also reviewed several roadside hydroseeding applications.

Roadside Hydroseeding in the Queen Charlotte Islands

The first hydroseeding on logging roads in the Queen Charlottes began in 1979. Two of the major forest companies with land tenures on the islands, MacMillan Bloedel Limited and Crown Forest Industries, contracted with Terrasol Revegetation and Erosion Control Services Ltd. to do 7 hectares of roadside seeding. The following year both forest companies converted existing fire tankers to hydroseeders. The third major forest licencee, Western Forest Products, purchased a hydroseeder developed by the B.C. Ministry of Forests (W.W. Carr) and Conair Aviation Ltd. From 1980 through 1983, 66 hectares of roadside seeding was completed. Labor and material costs using company equipment and personnel ranged from \$500 to \$850 per hectare. Costs for recent hydroseeding by MacMillan Bloedel on Vancouver Island were \$620 per hectare (\$420 materials, \$200 labor). The length of roadside yielding 1 hectare varied from 1 to 2.5 km, depending upon the exposed surface of cut and fill slopes.

Seed Coverage and Mixes

The seed mixes used by MB and others from 1979 through 1983 are given in Table 1, along with the mix for the current project. All mixes have been similar, with a grass/legume ratio of about 70:30 (by weight). The proportion of legumes in the mixture of the current project was increased to 40% (by weight) to provide additional N-fixation benefits to the seedlings.

All of the roadside areas that we viewed in September of 1983 had good coverage of grass and clover. They were dominated by Redtop, Creeping Red Fescue and Perrenial Ryegrass. White and Alsike clover also maintained

Table 1. Seed mixes used by forest licencees in the Queen Charlottes for hydroseeding.

SPECIES	% (Wt.) of Mix by Year MB 79/80	WFP 80	MB 81/82	CF 82/83	MB 84 (Sue L.)
Grasses					
Perennial Rye	10	20	20	5	30
Annual Rye	10			20	
Creeping Red Fescue	20	20	20	20	20
Red Top	5	5	5	5	10
Orchardgrass		5	20	15	
Meadow Foxtail	10	5	5	5	
Timothy	10				
Kentucky Bluegrass		15			
Grass Sub-Total	65	70	70	70	60
Legumes					
White Clover	5	10	15	10	10
Alsike Clover	10	10	15	20	20
Subterranean Clover	5				
Birdsfoot Trefoil					10
Sainfoil	15				
Red Clover		10			
Legume Sub-Total	35	30	30	30	40

good coverage in most areas. Personal observations during 1980-82 showed that these roadsides become a preferred grazing spot for deer.

I compared the seeding rate used in the Charlottes (84 kg/ha), with recommendations from other sources (Table 2). The rate falls within the range suggested by Carr (1980) for wet coastal B.C. of 50-100 kg/ha. Rates, of course, vary according to the composition of species in the mix with different size seed. These rates, however, are significantly greater than the maximum rates (35 kg/ha) suggested for roadside erosion control in coastal Oregon (Berglund 1976). The rationale given by Carr (1980) for

Table 2. Seeding rates used or recommended by various sources for roadside erosion control.

Roadside Truck Seedling	Seed (kg/ha)	Fertilizer (kg/ha)	Binder (kg/ha)	Mulch (kg/ha)
OSU Extension (Berglund 1976)[1]	17-35	N 45-90 P,K varies	ns[2]	ns
MB/CF (QCI) 1979 (Terrasol Contract)	84	370[3]	45[4]	112[5]
MB/CF (QCI) 1979 - 1983	84	370[6]	45	-
WFP (QCI) 1980 -	84	370[6]	56	-
Terrasol 1976 (Carr and Ballard 1980)	100	450[7]	33	670
B.C. Ministry of Forests (Carr 1980)	50-100	N 50-80 P 30-50 K 50-75	ns	ns
B.C. Ministry of Highways (A.D. Planiden, pers. comm. 1984)	84	225[8]	ns	1100[9]
B.C. Hydro (R. Roddick, pers. comm. 1984)	25	400[6]	34-67	900-1000
Richardson Seed Company (Newsletter, 1984)	56-84	ns	ns	ns

1 Based on an average 144 LPS/sq.ft. up to 300 LPS/sq.ft. maximum recommendation for W. Oregon, using the MB 1981/1982 species mix.

2 ns = not specified.

3 19-19-19 (N-P-K)

4 M-1 Binder (Terrasol Revegetation Erosion Control Ltd.)

5 Cellulose fibre

6 20-24-15

7 10-30-10

8 14-10-28

9 "Spra" Mulch, "Fibramulch", or "Silva-Fiber" average rate.

these high rates was: 1) seed is a small portion of the total cost of the operation so add plenty to ensure good coverage, 2) some seed is wasted as residue in the hydroseeder tank, and 3) some seed is damaged in agitation and pumping.

Fertilizer and binder rates used in the Charlottes were quite liberal. I have found 300 kg/ha of 20-24-15 to be adequate for roadcuts through gravelly, loamy textured glacial till. Binder rates of 25-40 kg/ha (10-15 kg per 500 gal. of slurry) proved adequate for steep roadcut applications this spring on Vancouver Island. Because binder is the most expensive component of the mixture, keeping rates as low as possible while still maintaining good tactifying and suspension qualities is an important economic consideration.

Helicopter Applications

The first helicopter seeding done in the Queen Charlottes was in June 1979 using a Hughes 500 helicopter and a monsoon bucket with a motorized propeller at the opening for spreading the slurry. This system was tried on several landslides near Haans Creek within MacMillan Bloedel's Hecate Division. Following this trial, Bill Marson of Queen Charlotte Helicopters and Bill Carr, contractor to the B.C. Ministry of Forests, modified the bucket to provide internal agitation and prevent settling of seed. This equipment was tested in May 1980 on Spur 29 of Crown Forest's Sandspit Operations and proved successful except for a problem with rotation of the bucket from the internal agitator (Carr and Marchant 1981). In April 1982, some different equipment was tried by Bill Carr and others near Squamish on the B.C. Mainland. A Simplex conventional dry-seeding bucket was used along with a new suspension agent -- J-Tac A.S. (Carr 1982). This method proved successful, without rotation or settling problems, and made use of readily available equipment.

We assessed the success of the helicopter hydroseeding in the Queen Charlottes in September 1983. The landslides on Spur 29 of Crown Forest have established a dense grass cover after four growing seasons. Small slumps continue to occur on the slope, but the soil eroded from these exposed areas is readily caught in the dense mat of grasses below. The vegetative cover appears to provide protection for tree seedlings planted on the slide from the adverse impact of erosion and slope movement and helps retain moisture on the site while its competitive influence has not seriously affected the seedlings. Seedlings had healthy green foliage, showing the benefit of fertilization and N-fixing legumes. Seedlings on similar slopes and soil without seeding showed poor vigor and color.

The helicopter seeded landslides near Haans Creek are steep-sided gullies, in contrast to the open slope debris slides of Spur 29. There is also less soil material and more exposed bedrock. The southerly exposure is more susceptible to summer drought than the northerly exposure of Spur 29. Consequently, grass cover is not as vigorous on the Haans slides, but the coverage is still substantial. Some natural seed-in of red alder has occurred.

Shrub Performance Trials

Six species of shrubs were planted on the Spur 29 slides in November 1980 with a total of 680 plants. Survival for large willow rooted cuttings, snowberry (Symphoricarpos albus), hardhack, dogwood (Cornus stolonifera), and salmonberry was 99-100% in June 1981. Willow sticks (55% survival) and thimbleberry (60% survival) did not do as well (Carr and Marchant 1981).

All of the shrubs observed in September 1983 had been browsed heavily by deer. A drier than normal summer in 1982 probably caused additional mortality and dieback (W.W. Carr, pers. comm.). Based on the performance of the species observed, willow and salmonberry show the most promise for future trials. Hardhack is a promising species for the bottom of gullies or lower portion of slides.

RESULTS AND DISCUSSION

Helicopter Hydroseeding

The hydroseeding operation at the Sue Lake slide was attempted in September 1983. Mechanical problems with the seeding bucket and poor weather conditions delayed the operation until early March 1984. A Bell 206 helicopter operated by Queen Charlotte Helicopters and a Chadwick seeding bucket rented from Okanagan Helicopters were used for the operation. The seeding bucket was filled from a pre-mixed 800 gallon capacity hydroseeder truck located on a road just below the slide. Table 3 gives details on the helicopter application, with data from two previous trials as a comparison. The average turn time of 5.7 minutes is quite close to that of previous trials. The first seven turns of the second tankful of slurry averaged 4.8 minutes per turn. Later turns were slower because the ground crew was directing the helicopter pilot to unseeded areas using radio contact. This was only partially successful due to the vantage point of the ground crew. A sketch map recording the area seeded as the operation progressed was found to be essential for keeping track of the areas covered. It also served as a record of areas that either received a double pass or were missed.

The actual application rate for the Sue Lake slide was somewhat greater than planned because only 1.5 ha of the 2.0 ha slide were covered. Seeding rates for the three trials in Table 3 range from 30 to 50 kg/ha. The actual amount of slurry applied per hectare, however, has varied substantially. The 1981 and 1982 trials used approximately one-third to one-fifth of the amount of slurry in the Sue Lake operation; consequently, this trial was a much "wetter" application than previously.

Seed Coverage

The seedling rate, based on the planned 40 kg/ha yields 638 seeds/sq.ft. or over 4 seeds per square inch. Actual seed counts were made from eight 50 x 50 cm screens placed from the base to top of the Sue Lake slide. The range in coverage was from 90 seeds/sq.ft. to 1300 seeds/sq.ft. The heavier coverage occurred on areas that received two passes. The Squamish J-Tac trial yielded about 144 seeds/sq.ft. (Carr 1982).

Foresters from MacMillan Bloedel's Queen Charlotte Division viewed the slide in July and observed the uneven coverage that the sampling screens had indicated. Some patches were missed entirely during the seeding. These should seed-in from the surrounding area with time. Coverage could be improved in future operations by including a dye in the slurry that would enable the helicopter pilot to see coverage more easily. A fluorescent orange dye used in chemical fire retardant aerial application

Table 3. Comparison of Sue Lake Helicopter Seeding with other trials.

	Sue Lake March 1984	Squamish (J-TAC)[1] April 1982	SPUR 29[2] May 1981
Area seeded	1.5 ha	1.6 ha	3.0 ha
Slurry applied	1500 gal.	320 gal.	1000 gal.
Slurry per hectare	1000 gal.	200 gal.	333 gal.
Materials*			
Fertilizer	20-24-15	19-19-19	20-24-15
Rate (kg/ha)	416 (312)	312 (320)	150
Seed-grass: Legume (by wt.)	60:40	70:30	70:30
Rate (kg/ha)	53 (40)	29 (38)	33
Binder	ECOLOGY M-1	J-TAC	ECOLOGY M-1
Rate (kg/ha)	40 (30)	15.6	18.3
% (by weight) of mix	0.9%	1.5%	1.2%
Application			
Total Flight Time	2.0 hrs	0.8 hrs	1.0 hrs
Average Payload	70 gal.	40 gal.	85 gal.
Number of Turns	21	8	12
Average Time Returns (minutes):	5.7	6.0	5.0
Filling of Bucket	2.0	2.0	1.0
Flight To/From site	3.3	3.5	3.0
Spreading Slurry	0.4	0.5	1.0
Equipment			
Helicopter	BELL 206	BELL 47-G3B2	HUGHES 500
Bucket	CHADWICK	SIMPLEX	QCH PROTOTYPE
Hydroseeder Truck	MB 800 gal.	AEROCON 800 gal.	CF 1000 gal.

* Rates given are actual and (plan).

[1] Carr 1982.

[2] Carr and Marchant 1981.

has been suggested. A co-pilot might also improve the operation, although this might necessitate a reduction in payload for some sites where lift is critical.

Tree and Shrub Planting

Planting occurred in April 1984. A 5 person contract crew was employed to plant the 3500 shrubs and 8500 sitka spruce seedlings. The overall productivity rate was 650 plants per manday. The patchwork of 50 plant blocks for the species performance trial, the large root systems on some shrub species, and the difficult footing on most of the slide lowered the productivity rate. Some damage occurred to the newly seeded grass and clover during planting. It would have been preferable to plant after the grass cover had been well established, but the availability of shrubs and trees made it impossible to postpone planting until the Fall. Had the original plan been successful, the seeding would have overwintered before planting. The weather during and after planting was cool and moist, making chances for survival favorable.

Application to Other Areas

Results from this project will be used to develop operational guidelines for our logging divisions for landslide reforestation and erosion control activities. Because of the high cost of helicopter seeding, its use will likely be confined to areas inaccessible to truck-mounted seeders where manual dry seeding is deemed unsuitable and where there are special aesthetic, productivity or fisheries concerns. The value of sitka alder and clover for biological nitrogen fertilization of disturbed or low fertility sites will also have application to our forestry operations on areas other than landslides.

ACKNOWLEDGMENTS

I would like to thank Bill Carr for his consultation during this stage of the project; Terry Rollerson and Steve Northway for their assistance in developing the project proposal; Ed Phillips and Dean Miller of Queen Charlotte Helicopters; Dave Dunkley and Jim Henry for their help during seeding operations; the staff of Queen Charlotte Woodlands Division of MacMillan Bloedel Limited for their cooperation and assistance; and Heather Kibbey for her work on Vancouver Island establishing legume trials.

This research project was funded in part under Section 88 of the Forest Act, as administered by the Ministry of Forests, in Smithers, B.C.

REFERENCES

Berglund, E.R. 1976. Seeding to control erosion along forest roads. Oregon State Univ. Extension Service Circular 885, Corvallis, Oregon, 19 pp.

Blaney, D.G. and G.E. Warrington. 1983. Estimating soil erosion using an erosion bridge. USDA Forest Service, Watershed Systems Development Group, 55 p.

Carr, W.W. 1980. Handbook for forest roadside surface erosion control. Land Management Report No. 4, B.C. Ministry of Forests, Victoria, B.C., 43 p.

Carr, W.W. 1982. Preliminary report: The use of J-TAC A.S. in aerial hydroseeding, initial test - 1982. B.C. Ministry of Forests Project E.P. 834: 02-02, 5 p.

Carr, W.W. and T.M. Ballard. 1980. Hydroseeding of forest roadsides in British Columbia for erosion control. J. Soil and Water Conservation 35(1): 33-35.

Carr, W.W. and C.J. Marchant. 1981. Erosion control in the Queen Charlotte Islands. In: Proceedings of the Can. Land Reclamation Conf., August 1981, Cranbrook, B.C., 28 p.

Miles, D.W.R., F.J. Swanson, and C.T. Youngberg. 1984. Effects of landslide erosion on subsequent Douglas-fir growth and stocking levels in the Western Cascades, Oregon. Soil Sci. Soc. Am. J. 48: 667-671.

Ranger, G.E. and F.F. Frank. 1978. The 3-F erosion bridge - a new tool for measuring soil erosion. State of California, Dept. of Forestry, Range Improvement Studies Report No. 23, 7 p.

Schiechtl, H. 1980. Bioengineering for Land Reclamation and Conservation. (Translation by N.K. Horstmann), Univ. of Alberta Press, Edmonton. 404 p.

Smith, R.B., P.R. Commandeur and M.W. Ryan. 1984. Vegetation succession, soil development and forest productivity on landslides, Queen Charlotte Islands, B.C., Canada. IUFRO Symposium on Effects of Forest Land Use on Erosion and Slope Stability, Honolulu, Hawaii, May 7-11, 1984.

THE USE OF CEMENT KILN BY-PASS DUST AS A LIMING MATERIAL IN THE REVEGETATION OF ACID, METAL-CONTAMINATED LAND.

Keith Winterhalder

Department of Biology, Laurentian University

SUDBURY, Ontario P3E 2C6

ABSTRACT

Cement kiln by-pass dusts from Canada Cement Lafarge Ltd. plants at Woodstock and Bath, Ontario, respectively, were tested as limestone substitutes in reclaiming acid, metal-contaminated soils from the Sudbury area. Laboratory, growth chamber and field trials showed that both dusts constituted effective liming materials at an application rate of approximately 10 t/ha. Toxic effects were found only in the case of Bath dust, at an application rate of 50 t/ha. In sandy soil, Bath dust at 50 t/ha also inhibited seed germination. This inhibition disappeared after a few days, presumably due to the leaching of soluble alkaline materials and chlorides. In pots, the addition of N-P-K fertilizer lessened the toxic effect of Bath dust, while in the field it converted the effect of the dust from inhibition to stimulation. These by-pass dusts have good potential as liming materials in reclaiming Sudbury's industrial barrens, but their caustic nature precludes their use at this time, in view of the predominantly manual application techniques that prevail.

INTRODUCTION

One hundred years of logging, fire, acidification by sulphur dioxide, particulate metal deposition and erosion have created extensive tracts of barren land surrounding the Sudbury nickel and copper smelters (Winterhalder, 1984). Following recent improvement in atmospheric quality, the principal factors limiting colonization now reside in the soil, mainly in the form of copper, nickel and aluminum toxicity. The soil can be detoxified by limestone application (Winterhalder, 1974), and since 1978 approximately 1000 hectares (2500 acres) have been revegetated by manual liming, fertilization and seeding (Winterhalder, 1983a). It has been shown (Winterhalder, 1983b) that both the calcium ions and the neutralization component of limestone are operative in the detoxification of Sudbury's toxic soils.

Fortunately, Sudbury's mining and smelting industry has been able to minimize the emission of toxic particulate wastes by the use of efficient electrostatic precipitators, making the soil toxicity problem a residual one that can be dealt with by the measures outlined above. Mill tailings, another major solid waste product, can also be rendered innocuous by revegetation (Peters, 1984), while slag is utilized as road building material. In the case of the cement industry, the major solid waste, highly alkaline by-pass dust, creates its own disposal problem. In Derbyshire, England, an effective solution has been to cover the lime waste with spent mushroom compost (Bradshaw & Chadwick, 1980). A 10 cm layer increases the carbonation rate of the underlying lime waste, allowing plants to root into it and producing excellent agricultural land.

In Ontario, it seemed appropriate to explore the possibility of another type of "recycling", once again using one waste product to counteract the effects of another one. Since the Sudbury barrens are in need of a material that provides both calcium ions and hydroxyl ions, it seemed logical to test cement kiln by-pass dust, an alkaline, calcium-rich material, as an ameliorant and limestone substitute.

MATERIALS AND METHODS - POT TRIALS

Soils.

Four soils were chosen to represent different sand, clay and organic matter contents. Each was both acid and metal-contaminated, and was taken from a barren or semi-barren site. The sample was taken from what might be considered as the "rooting zone" of most herbaceous plants (0-15 cm).

The soils were as follows:

Soil 1. A silty fine sand from the valley of Coniston Creek, 2 miles northeast of the Coniston smelter (Barren ground, pH 4.5).

Soil 2. A clay soil from Coniston, 1 mile south of the smelter (Barren ground, pH 4.5).

Soil 3. A sandy soil containing some organic matter, from near Wahnapitae, 3½ miles northeast of the Coniston smelter (semi-barren, pH 4.1).

Soil 4. A sandy soil containing some organic matter from the Skead area, 4 miles north-northeast of the Falconbridge smelter (semi-barren, pH 4.5).

Each soil was passed through a coarse sieve in order to remove large stones. A small sample of each soil was kept for later analysis if necessary.

Neutralizing Materials.

Two samples of by-pass dust were provided by Canada Cement Lafarge Ltd.. Chemical data on the materials, as provided by the company, are given in Table 1. In addition to the two dust samples, analytical grade calcium carbonate was used as a control liming material.

TABLE 1. Partial Chemical Analysis of By-pass Dust Samples

Component	Bath Dust	Woodstock Dust
SiO_2	11.3	16.0
Al_2O_3	2.5	2.3
Fe_2O_3	1.3	1.4
CaO	36.5	39.6
MgO	1.4	2.1
K_2O	5.0	7.7
Na_2O	1.2	0.8
SO_4	8.6	12.7
Cl	9.7	not determined
CO_2	10.4	not determined
pH	12.6	not determined

(pH determinations carried out at Laurentian University gave values of 11.2 $\pm$ 0.2 for both dusts)

The above data are not complete enough to predict the relative neutralizing power and toxicity of the two by-products.

Pots.

Three-inch plastic plant pots (soil capacity 160 ml) were used, the three drainage holes being covered by filter paper.

Incorporation of neutralizing materials.

The neutralizing material was thoroughly mixed into the dry soil by shaking them together in a plastic bag before replacing the soil in its pot.

Soil pH Determination.

Soil was wetted to the saturation percentage point (Jackson, 1958), and the pH determined on the paste with a glass electrode pH meter.

Plants.

Redtop (Agrostis gigantea), a grass species widely used in land reclamation, was grown from commercially available seed. A standard measure of seeds (0.2 ml) was sprinkled onto the soil surface.

Incubation and Growth Conditions.

Incubation without seed and initial germination of seed were carried out on a laboratory bench at approximately 25°C, the pots being covered by dark plastic sheeting.

Growth was carried out in a growth chamber set for a 16 hours of daylight/8 hours of darkness cycle, the day temperature being 25°C, the night temperature 15°C.

Criteria of Plant Growth.

At the end of six weeks, plants were observed for average height, maximum leaf width, purpling, chlorosis, and chlorotic banding. The tops were clipped as close as possible to the soil surface, dried in an oven at 80°C and weighed.

INCUBATION EXPERIMENTS

In the first experiment, each of the four soils was incubated with eight levels of by-product, varying from zero to an equivalent of 50 t/ha, for a period of five days. Final soil pH values are given in Tables 2a - 2d.

TABLE 2a. FINAL pH OF CLAY SOIL FROM SOUTH OF CONISTON AFTER INCUBATING WITH VARIED AMOUNTS OF DUST. (n=1)

g of dust	Equivalent in t/ha	Woodstock dust	Bath dust
0	0	(5.4)*	4.5
0.1	1.0	4.5	4.4
0.25	2.5	5.3	4.8
0.5	5.0	5.5	5.5
1.0	10.0	6.0	6.1
1.5	15.0	6.2	7.0
2.0	20.0	7.1	(6.2)*
5.0	50.0	7.4	7.7

TABLE 2b. FINAL pH OF SANDY SOIL FROM CONISTON-GARSON ROAD AFTER INCUBATING WITH VARIED AMOUNTS OF DUST. (n=1)

g of dust	Equivalent in t/ha	Woodstock dust	Bath dust
0	0	4.8	5.0
0.1	1.0	5.6	5.2
0.25	2.5	5.8	5.6
0.5	5.0	6.3	6.2
1.0	10.0	6.6	6.6
1.5	15.0	6.9	7.1
2.0	20.0	6.9	7.3
5.0	50.0	7.7	8.6

TABLE 2c. FINAL pH OF SANDY, HUMIC SOIL FROM SOUTH OF SKEAD (n = 1)

g of dust	Equivalent in t/ha	Woodstock dust	Bath dust
0	0	4.5	4.7
0.1	1.0	4.7	4.7
0.25	2.5	5.1	5.1
0.5	5.0	5.7	5.4
1.0	10.0	6.3	6.0
1.5	15.0	6.6	6.2
2.0	20.0	6.8	6.7
5.0	50.0	7.4	8.1

TABLE 2d. FINAL pH OF SANDY, HUMIC SOIL FROM NORTH OF WAHNAPITAE (n = 1)

0	0	4.1	4.2
0.1	1.0	4.6	4.6
0.25	2.5	(4.1)*	4.6
0.5	5.0	5.1	5.0
1.0	10.0	5.9	5.7
1.5	15.0	6.8	6.2
2.0	20.0	7.0	6.3
5.0	50.0	7.3	8.0

* These highly inconsistent values are almost certainly due to experimental error.

A desirable pH of around 6.5 was obtained at between 5 and 10 t/ha in the sandy soil, between 10 and 20 t/ha in the clay soil and between 15 and 20 t/ha in the soil with high organic content. At 50 t/ha, excessively high pHs for plant growth (pH 8 and above) were obtained with the Bath product.

At the termination of this trial, it was converted into a preliminary growth trial by applying Redtop seeds and growing the plants for 30 days. Since the experiment was not replicated, results are not tabulated in this report, but some definite trends were evident. In general, Woodstock dust gave increased plant growth up to at least 10 t/ha, with no significant growth depression even at a 50 t/ha application rate. The Bath product gave a similar growth increase up to 10 t/ha, but at 50 t/ha showed a highly toxic reaction, with plant growth reduced below the control level.

In the second incubation experiment, calcium carbonate was included as a control ameliorant, and was compared with the Bath dust only. Each of the four soils was incubated with four levels of additive, representing the equivalent of 10 t/ha to 25 t/ha. This experiment was designed to work within the non-toxic range, so that the effectiveness of the by-product could be compared with that of calcium carbonate. After five days, pH was measured in each pot. Final soil pH levels are shown in Tables 3a to 3d..

Calcium carbonate appeared to be somewhat more effective than Bath dust in neutralizing the soil, e.g. in the clay soil, 15 t/ha of Bath dust were required to achieve a desirable pH of 6.5, whereas only 10 t/ha of $CaCO_3$ were required to achieve an almost equivalent pH of 6.3.

Once again, seeds were sown and the plants grown for 30 days. Within the limits of this unreplicated experiment, growth was quite good

TABLE 3a. FINAL pH OF CLAY SOIL FROM SOUTH OF CONISTON AFTER INCUBATING WITH VARIED AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent in t/ha	Bath dust	$CaCO_3$
1.0	10.0	5.6	6.3
1.5	15.0	6.5	7.1
2.0	20.0	6.1	7.2
2.5	25.0	6.8	6.8

TABLE 3b. FINAL pH OF SANDY SOIL FROM CONISTON-GARSON ROAD AFTER INCUBATING WITH VARIED AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent t/ha	Bath dust	$CaCO_3$
1.0	10.0	6.5	7.3
1.5	15.0	7.0	7.3
2.0	20.0	7.5	7.5
2.5	25.0	7.5	7.5

TABLE 3c. FINAL pH OF SANDY, HUMIC SOIL FROM SOUTH OF SKEAD AFTER INCUBATING WITH VARYING AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent in t/ha	Bath dust	$CaCO_3$
1.0	10.0	6.2	7.2
1.5	15.0	6.8	7.4
2.0	20.0	7.0	7.5
2.5	25.0	7.3	7.5

TABLE 3d. FINAL pH OF SANDY, HUMIC SOIL FROM NORTH OF WAHNAPITAE AFTER INCUBATING WITH VARYING AMOUNTS OF BATH DUST AND $CaCO_3$ (n = 1)

g of dust	Equivalent in t/ha	Bath dust	$CaCO_3$
1.0	10.0	5.9	6.8
1.5	15.0	6.3	7.3
2.0	20.0	6.8	7.6
2.5	25.0	7.2	7.6

under all treatments and no definite trends emerged, suggesting that by-pass dust and calcium carbonate are equally effective liming materials when application rates are kept within the by-product's non-toxic range.

GROWTH EXPERIMENT AT OPTIMAL AMELIORANT LEVELS

Each soil was mixed with calcium carbonate, Woodstock dust and Bath dust equivalent to 5, 10 and 20 t/ha, respectively and sown with Redtop seed. Each treatment was replicated five times. Final soil pH values and dry weight production of tops are given in Tables 4a to 4d.

In all cases, the cement kiln dusts were effective in promoting plant growth at the levels used. Woodstock dust was approximately equal to calcium carbonate in its effectiveness, Bath dust slightly less so.

GROWTH EXPERIMENT AT POTENTIALLY TOXIC AMELIORANT LEVELS

This experiment was designed to explore the relative toxicities of the by-products at high application rates. Each soil was treated with calcium carbonate, Woodstock dust and Bath dust at levels equivalent to 30, 40 and 50 t/ha, respectively, and sown with Redtop seed. Final soil pH values and dry weight of tops are shown in Tables 5a to 5d.

In all soils growth enhancement was found in all treatments except Bath dust at 40 and 50 t/ha, which depressed growth. In the sandy Coniston soil, 50 t/ha of Bath dust even inhibited germination.

GROWTH EXPERIMENT AT POTENTIALLY TOXIC AMELIORANT LEVELS, WITH VARIED LEACHING REGIMES AND INCUBATION TIMES

This experiment was designed to test two hypotheses. It has been

TABLE 4a. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON CLAY SOIL FROM SOUTH OF CONISTON AFTER TREATMENT WITH VARYING AMOUNT OF CALCIUM CARBONATE, BATH DUST AND WOODSTOCK DUST. (n = 5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	5.4	0.514 ± 0.025	4.7	0.400 ± 0.045	4.9	0.484 ± 0.035
1.0	10.0	6.6	0.538 ± 0.039	5.3	0.408 ± 0.032	5.4	0.500 ± 0.013
2.0	20.0	7.5	0.632 ± 0.027	6.4	0.404 ± 0.029	6.5	0.548 ± 0.021

TABLE 4b. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY SOIL FROM THE CONISTON-GARSON ROAD AFTER TREATMENT WITH VARYING AMOUNTS OF CALCIUM CARBONATE, BATH DUST AND WOODSTOCK DUST. (n = 5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	6.6	0.072 ± 0.006	6.1	0.110 ± 0.003	6.2	0.066 ± 0.007
1.0	10.0	7.5	0.068 ± 0.007	6.7	0.088 ± 0.002	6.8	0.074 ± 0.011
2.0	20.0	7.6	0.048 ± 0.004	7.2	0.054 ± 0.007	7.2	0.092 ± 0.009

TABLE 4c. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY, HUMIC SOIL FROM SOUTH OF SKEAD AFTER TREATMENT WITH VARYING AMOUNTS OF CALCIUM CARBONATE, BATH DUST AND WOODSTOCK DUST. (n=5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	6.0	0.378 ± 0.023	5.2	0.268 ± 0.011	5.3	0.310 ± 0.009
1.0	10.0	6.9	0.316 ± 0.012	6.1	0.286 ± 0.025	6.0	0.360 ± 0.016
2.0	20.0	7.5	0.308 ± 0.011	6.8	0.308 ± 0.023	6.7	0.356 ± 0.017

TABLE 4d. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY, HUMIC SOIL FRON NORTH OF WAHNAPITAE AFTER TREATMENT WITH VARYING AMOUNTS OF CALCIUM CARBONATE' BATH DUST AND WOODSTOCK DUST (n=5)

g of material	Equivalent in t/ha	$CaCO_3$		Bath		Woodstock	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
0.5	5.0	5.3	0.304 ± 0.026	5.0	0.378 ± 0.060	4.8	0.600 ± 0.023
1.0	10.0	6.2	0.540 ± 0.017	5.4	0.544 ± 0.058	5.2	0.642 ± 0.011
2.0	20.0	7.3	0.492 ± 0.023	6.2	0.632 ± 0.032	6.4	0.750 ± 0.044

In an Analysis of Variance, soil, neutralizer type and application rate effects were highly significant with respect to biomass production, as were soil-neutralizer and soil-application rate interactions. Although the neutralizer type-application rate interaction was non-significant, the soil-neutralizer type-application rate interaction was highly significant.* *($p < 0.01$)

TABLE 5a. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON CLAY SOIL FROM SOUTH OF CONISTON AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	30	7.4	0.777 ± 0.015	7.0	0.680 ± 0.049	7.0	0.570 ± 0.006
4.0	40	7.5	0.740 ± 0.026	7.2	0.647 ± 0.032	7.0	0.320 ± 0.058
5.0	50	7.5	0.727 ± 0.048	7.0	0.733 ± 0.086	7.0	0.190 ± 0.059

TABLE 5b. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY SOIL FROM THE CONISTON-GARSON ROAD AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	30	7.5	0.050 ± 0.006	7.2	0.097 ± 0.007	7.3	0.080 ± 0.012
4.0	40	7.5	0.040 ± 0.006	7.2	0.100 ± 0.006	7.4	0.023 ± 0.003
5.0	50	7.3	0.067 ± 0.012	7.3	0.087 ± 0.003	7.5	0.003 ± 0.003

TABLE 5c. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY, HUMIC SOIL FROM SOUTH OF SKEAD AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	15	6.2	0.313 ± 0.007	6.7	0.513 ± 0.037	6.5	0.317 ± 0.015
4.0	20	6.6	0.330 ± 0.023	6.8	0.437 ± 0.026	6.7	0.113 ± 0.020
5.0	25	6.9	0.320 ± 0.000	6.9	0.460 ± 0.030	7.1	0.053 ± 0.039

TABLE 5d. MEAN SOIL pH AND MEAN BIOMASS OF TOPS (DRY WEIGHT IN GRAMS) ON SANDY SOIL FROM THE CONISTON-GARSON ROAD AFTER TREATMENT WITH VARYING HIGH LEVELS OF CALCIUM CARBONATE AND KILN DUST. REPLICATED THREE TIMES.

g of material	Equivalent in t/ha	$CaCO_3$		Woodstock		Bath	
		pH	Weight ± S.E.	pH	Weight ± S.E.	pH	Weight ± S.E.
3.0	15	7.6	0.580 ± 0.026	7.0	0.937 ± 0.045	7.0	0.453 ± 0.059
4.0	20	7.6	0.527 ± 0.038	7.0	0.803 ± 0.030	7.0	0.177 ± 0.032
5.0	25	7.5	0.507 ± 0.032	7.1	0.840 ± 0.025	7.0	0.107 ± 0.037

In an Analysis of Variance, soil, neutralizer and level were highly significant effects ($p < .01$) with respect to biomass, as were the soil-neutralizer and neutralizer-level interactions, while the soil-neutralizer-level interaction was significant at the 0.1 probability level. With respect to pH, soil, neutralizer, level, soil-neutralizer, soil-level, neutralizer-level and soil-neutralizer-level effects were all highly significant ($p < .01$)

observed that germination is delayed at high levels of Bath dust application, but that it does finally occur. There are two possible explanations for this:

1. That the free alkali initially inhibiting germination reacts with the acid soil over a period of time. Once neutralized, the alkali is no longer inhibitory.
2. That the toxic principle, which may be alkali, chloride or both, is leached out of the soil after a period of time.

Bath and Woodstock dusts were separately mixed with Skead soil at a rate equivalent to 50 t/ha. Two leaching regimes were used, one with free drainage, the other with recycling of leachate. Furthermore, the incubation period prior to sowing seeds was varied from zero to 12 days.

Mean soil pH values at the end of the experiment are shown in Table 6, while Table 7 depicts dry weights of tops. In terms of soil pH, leaching regime appears to have no effect in the case of Woodstock dust. In the case of Bath dust, however, it seems, rather surprisingly, that the recycling treatment produces a slightly lower pH than does the free drainage treatment. This suggests that chloride, rather than alkali, is being leached.

Dry weight data shown in Table 7 indicate a very different response to leaching regime in the two dust treatments. In the case of the Woodstock dust treatment, recycling is consistently beneficial to dry weight production, whereas in the case of the Bath dust treatment it is consistently deleterious. This is consistent with the idea that the leaching out of soluble materials, probably chlorides, is the most important explanation of delayed germination. Incubation time, in itself, does not appear to influence dry weight production.

TABLE 6. MEAN pH OF SKEAD SOIL AFTER TREATMENT WITH FIVE GRAMS PER POT (= 50 t/ha) OF WOODSTOCK KILN DUST AND BATH KILN DUST, RESPECTIVELY, UNDER TWO LEACHING REGIMES.

DUST TYPE	LEACHING REGIME	INCUBATION TIME BEFORE SOWING SEEDS IN DAYS					$\bar{x}$
		0	3	6	9	12	
Woodstock	Free	7.3	7.4	7.6	7.5	7.3	7.5
	Recycled	7.3	7.4	7.6	7.4	7.3	7.4
Bath	Free	7.9	8.0	7.8	7.-	6.8	7.6
	Recycled	7.5	7.7	7.5	7.1	7.0	7.4

In an Analysis of Variance, dust type, leaching regime and incubation time all had a highly significant effect on pH ($p < .01$), as did all two and three-way interactions.

TABLE 7. MEAN DRY WEIGHT IN GRAMS PER POT OF REDTOP PLANTS GROWN IN SKEAD SOIL UNDER TWO LEACHING REGIMES AND FIVE INCUBATION PERIODS BEFORE SOWING (MEAN OF FIVE REPLICATES ± STANDARD ERROR).

DUST TYPE	LEACHING REGIME	INCUBATION TIME BEFORE SOWING (DAYS)				
		0	3	6	9	12
Woodstock	Free	.518 ± .022	.434 ± .029	.474 ± .025	.548 ± .032	.512 ± .028
	Recycled	.534 ± .048	.460 ± .027	.604 ± .027	.652 ± .027	.642 ± .055
Bath	Free	.132 ± .022	.162 ± .028	.226 ± .025	.184 ± .004	.168 ± .028
	Recycled	.104 ± .015	.080 ± .024	.210 ± .038	.106 ± .016	.060 ± .027

In an Analysis of Variance, dust type and incubation time both had a highly significant effect on biomass ($p < .01$), as did dust type/incubation time and dust type/leaching regime interactions.

GROWTH EXPERIMENT IN FERTILIZED SOIL

Previous experiments have been carried out on unfertilized soil, since liming alone is sufficient to overcome the single overriding factor limiting plant establishment and growth - soil toxicity. The normal practice in reclaiming these soils, however, is to apply an N-P-K fertilizer in addition to the limestone, phosphorus deficiency being a secondary limiting factor (Winterhalder, 1975). Since a number of interactions are possible between liming material and fertilizer, it seemed desirable to determine whether the effects of the ameliorants on plant growth were any different in a fertilized soil from those in an unfertilized soil.

Each soil was treated with calcium carbonate, Bath dust and Woodstock dust, respectively, at levels equivalent to 0, 20 and 50 t/ha, and sown with Redtop seed. 0.1 g pulverized C.I.L. "Gardenite" was mixed into each pot, which was then seeded to Redtop. Mean final soil pH values are shown in Table 8 and mean dry weights of tops in Table 9.

Once again, pH figures show Bath dust to be the most effective neutralizer. At high levels, however, it is clearly deleterious to plant growth, particularly in sandy soils that lack humus or clay. The moderating effect of fertilizer on Bath dust toxicity can be seen, however, if we compare dry weight reduction from 20 t/ha to 50 t/ha in the first incubation experiment (no fertilizer) with the dry weight reduction from 20 to 50 t/ha in the fertilizer experiment (Table 10).

TABLE 8. MEAN pH OF FOUR FERTILIZED SUDBURY AREA SOILS AFTER INCUBATION WITH THREE LEVELS OF CALCIUM CARBONATE, WOODSTOCK KILN DUST AND BATH KILN DUST, RESPECTIVELY. (MEAN OF THREE REPLICATES).

SOIL TYPE	LOCATION	RATE	NEUTRALIZER		
			$CaCO_3$	Woodstock dust	Bath dust
Clay	Coniston	0 t/ha	3.6	4.2	3.7
		20 t/ha	6.5	5.9	6.1
		50 t/ha	6.8	7.0	7.2
Sand	Coniston-Garson	0 t/ha	5.3	4.8	5.4
		20 t/ha	7.3	7.1	7.1
		50 t/ha	7.5	7.5	7.7
Sand with Humus	Skead	0 t/ha	4.6	4.6	5.2
		20 t/ha	7.4	7.0	6.9
		50 t/ha	7.4	7.6	8.0
Sand with Humus	Wahnapitae	0 t/ha	4.8	4.6	4.5
		20 t/ha	7.5	6.7	6.2
		50 t/ha	7.6	7.4	7.7

In an Analysis of Variance, soil and level effects, as well as soil-level, soil-neutralizer, neutralizer-level and soil-neutralizer-level interactions are highly significant ($p < .01$), while neutralizer alone is only significant at the $p < .05$ level.

TABLE 9. MEAN DRY WEIGHTS IN GRAMS OF REDTOP PLANTS GROWN IN FOUR FERTILIZED SUDBURY AREA SOILS TREATED WITH THREE LEVELS OF CALCIUM CARBONATE, WOODSTOCK KILN DUST AND BATH KILN DUST, RESPECTIVELY. MEANS ARE OF THREE REPLICATES (± STANDARD ERROR).

SOIL TYPE	LOCATION	RATE	NEUTRALIZER		
			$CaCO_3$	Woodstock dust	Bath dust
Clay	Coniston	0 t/ha	0.240±.036	0.267±.052	0.210±.032
		20 t/ha	1.080±.232	1.033±.137	0.840±.106
		50 t/ha	1.127±.119	0.877±.201	0.623±.145
Sand	Coniston-Garson	0 t/ha	0.207±.024	0.153±.003	0.187±.041
		20 t/ha	0.237±.023	0.207±.063	0.203±.049
		50 t/ha	0.230±.020	0.170±.012	0.133±.020
Sand with Humus	Skead	0 t/ha	0.207±.052	0.237±.035	0.237±.066
		20 t/ha	0.403±.072	0.380±.042	0.300±.031
		50 t/ha	0.430±.075	0.380±.069	0.323±.052
Sand with Humus	Wahnapitae	0 t/ha	0.170±.015	0.147±.047	0.127±.023
		20 t/ha	1.020±.147	0.967±.145	0.497±.027
		50 t/ha	1.063±.167	0.910±.123	0.410±.096

In an Analysis of Variance, soil, neutralizer and level effects, as well as soil-neutralizer, soil-level and neutralizer-level interactions are highly significant ($p < .01$), while the soil-neutralizer-level interaction is significant at the $p < .05$ level.

TABLE 10. DRY WEIGHT PRODUCTION BY REDTOP SHOOTS AT 50 t/ha BATH DUST APPLICATION RATE EXPRESSED AS A PERCENTAGE OF DRY WEIGHT PRODUCTION AT 20 t/ha BATH DUST APPLICATION RATE

	Unfertilized	Fertilized
Clay Soil	5.2	74.0
Sandy Soil	20.0	65.0
Sandy, Humic Soil	22.0	104.0
Sandy, Humic Soil	5.9	84.0
Mean	13.3	80.1

It seems clear from this rather crude comparison that the depressive effect of fresh Bath dust on growth is much less severe when fertilizer is also used.

FIELD EXPERIMENTS

Materials and Methods.

Sites.

Two field sites were chosen, one being a level sandy area in the Coniston Creek valley, four km northeast of Coniston (called the "Coniston site"). The second site, also barren, was a stony hilltop 7 km northeast of Coniston (called the "Garson site").

Neutralizing materials.

The two kiln dusts used were from Woodstock and Bath, as described in the section on Pot Trials. The calcium carbonate was in this case pulverized limestone as used in the Sudbury Regional Land Reclamation

Programme. All three neutralizing materials were applied at a rate of 4.94 t/ha (2 tons/acre) at the Coniston site and 12.35 t/ha (5 tons/acre) at the more colloid-rich Garson site (i.e., .49 & 1.24 kg/m^2 respectively).

Fertilizer.

F.I.L. "Seeder-Sodder" (5-20-0) at a rate of 560 kg/ha (i.e., 56 g/m^2).

Incorporation of fertilizer and neutralizing materials.

In the case of the stone-free Coniston site, the soil was roughened by raking to a depth of 10 - 15 cm, then the ameliorant was raked in. In the case of the stony Garson site, however, the ameliorant was applied to the surface.

Plants.

As in the case of Pot Trials, Redtop was used. Seed was applied at 45 kg/ha (i.e., 4.5 g/m^2). At the Coniston site they were raked in to a depth of 2.5 cm, while at the Garson site they were applied to the surface.

C/W Factor.

Since percent cover and dry weight production represent two different and equally important criteria of revegetational success, a factor was devised in which each criterion was represented at equal weight. This Cover/Dry Weight (C/W) factor was derived as follows:

$$\text{C/W Factor} = \frac{\text{Relative \% cover + Relative Dry Weight}}{2}$$

The Relative Percent Cover was obtained as follows:

$$\text{R.P.C.} = \frac{\text{Mean \% cover for one treatment}}{\text{Total of all mean percent covers}} \times 100$$

Relative Dry Weight was calculated in the same way. Note that R.P.C., R.D.W. and C/W Factor are all percentages.

Experimental Design.

The experiment was set up using 1 m^2 plots in a randomized block design, and 5 replicates of each treatment combination at Coniston, 2 replicates at Garson (due to lack of space).

1 species x 2 fertilizer regimes x 4 neutralizer regimes
x 5 replicates = 40 plots (Coniston)

1 species x 2 fertilizer regimes x 4 neutralizer regimes
x 2 replicates = 16 plots (Garson)

The experiments were set up and seeded in late August, 1980. This has been found to be the best season for establishing herbaceous plants in the Sudbury area. Percent cover was determined in each plot, and above-ground parts harvested for biomass (standing crop) determination in July, 1981.

Results.

Percent cover, biomass and cover/weight factors are shown in Tables 11 & 12.

In Coniston soil, the importance of low nutrient status is obvious from the great differential in response to neutralization between unfertilized and fertilized soils. In both unfertilized and fertilized soil, the best response is to Woodstock dust.

In Garson soil, the response differential between unfertilized and fertilized soil is not so great, but it still exists. It is interesting to note, however, that in the case of Bath dust, the effect seems to be transformed from an inhibitory one to a stimulatory one by the addition of fertilizer. In fact, the best growth of all treatments is obtained on fertilized soil treated with Bath dust. Although only based on two replicates, the difference between unfertilized/Bath and fertilized/Bath treatments is striking and, as far as it goes, consistent.

The results of this trial point to the value of using the kiln dusts along with fertilizer, not only for the sake of increased yields, but because the ferlitizer appears to have a modifying effect on the potentially toxic properties of the Bath dust.

TABLE 11. MEAN PERCENT COVER AND MEAN ABOVE GROUND DRY WEIGHT OF PLANTS FROM CONISTON FIELD EXPERIMENT (BASED ON FIVE REPLICATES)

FERTILIZER REGIME	NEUTRALIZER	$\bar{x}$ % COVER AND S.E.	$\bar{x}$ DRY WEIGHT (g) AND S.E.	C/W FACTOR
Not Fertilized	Control	1.4 ± 0.4	0.6 ± 0.3	0.3
	Limestone	10.8 ± 3.1	6.8 ± 2.0	2.6
	Woodstock	13.8 ± 5.8	9.3 ± 3.7	3.3
	Bath	8.2 ± 3.4	6.4 ± 1.8	2.0
Fertilized	Control	39 ± 7.8	62.6 ± 9.7	12.3
	Limestone	69 ± 7.0	133.6 ± 25.9	25.2
	Woodstock	72 ± 3.7	206.0 ± 16.6	30.3
	Bath	58 ± 10.1	162.6 ± 32.5	24.2

In an analysis of variance, fertilizer and neutralizer effects, as well as fertilizer-neutralizer interaction, were significant ($p > .012$) in the case of biomass, while only fertilizer and neutralizer were significant ($p > .012$) in the case of percent cover. Using Duncan's Multiple Range Test ($p > .1$), on unfertilized and fertilized plots, mean biomass values fall into two subsets, indicating that the effects of the three neutralizers on biomass do not differ significantly from one another, whereas they all difer significantly from that of the control.

TABLE 12. MEAN PERCENT COVER AND MEAN ABOVE-GROUND DRY WEIGHT OF PLANTS FROM GARSON FIELD EXPERIMENT (BASED ON TWO REPLICATES).

FERTILIZER REGIME	NEUTRALIZER	$\bar{x}$ % COVER	$\bar{x}$ DRY WEIGHT (g)	C/W FACTOR
Not Fertilized	Control	0.5	0	0.1
	Limestone	30	34	12.9
	Woodstock	44	14	13.2
	Bath	8	14	4.3
Fertilized	Control	2	5	1.3
	Limestone	20	50	13.4
	Woodstock	45	94	26.2
	Bath	50	102	28.8

DISCUSSION

Both growth chamber and field trials suggest that cement kiln by-pass dusts have good potential as limestone substitutes in the revegetation of acid, metal-contaminated land. There are, however, several aspects of the kiln dusts' properties that necessitate somewhat more care in their use than that required in the case of ground limestone. For example:

a. Because of the potential for inhibiting germination and growth that some dusts (e.g. Bath) possess, the application level should be kept within the non-toxic limits (below 50 t/ha) or application should be carried out several weeks before seeding or both of the above. Purdy (1980), in growth chamber trials on sand and tailings at Falconbridge Nickel Mines Ltd., reached a similar conclusion. Indeed, he found that the germination and survival rates of Fall Rye (Secale cereale) were reduced at or about an application rate as low as 10 t/ha.

b. The crusting on the surface of the soil that occurs on contact with moisture has the potential to create a barrier to germination and growth, which may mean that the dusts do not lend themselves to surface application at high application rates. In the Garson field trial, which employed surface application, crusting did occur, but the crust soon cracked and seedlings were able to emerge. Allowing several weeks to elapse between dust application and seeding, as suggested above, might ensure that some breakup of the crust had occurred by this time. In non-stony areas, where the neutralizing agent is worked into the soil, the crusting problem does not arise. As pointed out by Purdy, however, the tendency of the dust to crust on contact with moisture might create serious problems in machine spreading. He suggests that the dust might be pelletized for spreading, but such a process would probably be technically difficult and therefore expensive.

C. Because of its caustic nature, the material could not be used in the current Sudbury Regional Land Reclamation Programme, in which limestone is spread by hand. Even loading and spreading such a material would be a potential health hazard to operators because of its dusty consistency.

d. As pointed out by Purdy, the by-pass dust possesses one third the density of ground limestone, increasing spreading costs.

e. In view of the significant alkali and chloride content of the waste, there is some potential for a salinity problem, but this is unlikely to be a serious consideration in a climate in which precipitation exceeds evapotranspiration such as that of the Sudbury area.

On the positive side, it should be noted that the dusts would be available without cost from the cement manufacturer, although the transportation costs would probably limit the economic feasibility of their use in the Sudbury area. Perhaps more important is the fact that the use of these dusts to counteract smelter-emitted pollution would be a fine example of appropriate technology, in which one waste product is used to counteract the harmful effects of another waste product, thereby achieving two waste disposal objectives in a single act. Such procedures, while desirable, are rare in waste disposal practice, except in the case of sewage sludge, either in raw or in composted form (e.g. Murray, Townsend & Sopper, 1981; Stucky, Bauer & Lindsey, 1980; Sutton & Vimmerstedt, 1973). In fact, in 1973 a consultant's report (Dillon, 1973) recommended the installation of a garbage grinding facility and ground garbage/sewage sludge composting plant for Sudbury, the resulting compost to be used in land reclamation. Although the project was never funded, preliminary work by the present author (Winterhalder, et al., 1976 and unpublished data) indicate that such a compost would be highly beneficial in reclaiming Sudbury's acid, metal-contaminated soils. With respect to the use of cement kiln dusts in land reclamation, however, no previously published reports on this subject exist, to the knowledge of the present author. The closest parallel can be drawn with the work of Gemmell (1981), who used two types of industrial lime waste ("dried calcareous slurry" and Leblanc wastes, respectively) in reclamation experiments on colliery spoil in the U.K. The success of their experiments was later confirmed by large-scale reclamation. Their wastes lacked the potentially toxic alkalies and chlorides present in cement kiln wastes, and they found that particle size, a factor not considered in the present report, was the largest single arbiter of short-term effectivity.

In conclusion, it appears that the possibility of utilizing industrial lime wastes, particularly those from the cement industry, has not received the attention that it deserves. This preliminary investigation strongly supports the feasibility of using cement kiln by-pass dust as a limestone substitute, but draws attention to certain economic and technological problems that would have to be overcome before its use would be appropriate in the Sudbury Regional Land Reclamation Programme.

ACKNOWLEDGEMENTS

This project was initiated by and funded through Canada Cement Lafarge Ltd. The conscientious technical assistance of Marlies Schoenefeld is gratefully acknowledged.

REFERENCES

BRADSHAW, A.D. & M.J. CHADWICK. 1980. The Restoration of Land. Univ. of California Press: Berkeley. 317 pp.

DILLON, M.M. 1973. Waste management study for the Regional Municipality of Sudbury. Consultant's Report to the Region.

GEMMELL, R.P. 1981. The reclamation of acidic colliery spoil II. The use of lime wastes. J. Applied Ecology 18:879-887.

JACKSON, M.L. 1958. Soil Chemical Analysis. Constable: London. 498 pp.

MURRAY, D.T., S.A. TOWNSEND & W.E. SOPPER. 1981. Using sludge to reclaim mine land. Biocycle 22(3):48-55.

PETERS, T.H. 1984. Rehabilitation of mine tailings: A case of complete ecosystem reconstruction and revegetation of industrially stressed lands in the Sudbury area, Ontario. Canada. IN: (Ed.) Sheehan, P.J. et al., Effects of Pollutants at the Ecosystem Level, Wiley: NY pp. 403-421.

PURDY, D.L. 1980. Cement kiln by-pass dust as a soil conditioner. Internal Report, Falconbridge Nickel Mines Ltd. 5 pp.

STUCKY, D.J., J.H. BAUER & T.C. LINDSEY. 1980. Restoration of acidic mine spoils with sewage sludge ; Revegetation. Recl. Review 3:129-139.

SUTTON, P. & J.P. VIMMERSTEDT. 1973. Treat stripmine soils with sewage sludge. Ohio Report 58:121-123.

WINTERHALDER, K. 1974. Reclamation studies on industrial barrens in the Sudbury area. Proc. 4th Ann. Workshop, Ont. Cover Crop Committee, Guelph. pp. 1-2.

WINTERHALDER, K. 1975. Reclamation of industrial barrens in the Sudbury area. Transactions Ann. Meeting, Ontario Chapter, Can. Soc. of Env. Biologists, Sudbury, February 1975. pp. 64-72.

WINTERHALDER, K. 1983a. The use of manual surface seeding, liming and fertilization in the reclamation of acid, metal-contaminated land in the Sudbury, Ontario mining and smelting region of Canada. Environmental Technology Letters 4:209-216.

WINTERHALDER, K. 1983b. Limestone application as a trigger factor in the revegetation of acid, metal-contaminated soils of the Sudbury area. Proc. 8th Ann. Meeting, Can. Land Reclamation Assoc., Waterloo, August 1983. pp. 201-212.

WINTERHALDER, K. 1984. Environmental degradation and rehabilitation in the Sudbury area. Laurentian University Review 16(2):15-47.

WINTERHALDER, K., I.A. McAULEY, S.M. McGINN, L.A. MICHELUTTI & S.S. RAPUNDALO. 1976. Composting of municipal wastes for use in the reclamation of industrial barrens. Proc. 1st Ann. Meeting, Can. Land Reclamation Assoc., Guelph, November 1976. 1 p.

MANAGING MINESOIL DEVELOPMENT FOR PRODUCTIVE RECLAIMED LANDS

by

WILLIAM SCHAFER[1]

ABSTRACT

Fears that disturbance of the soil system through mining could result in an overall decline in productivity have been common. To understand the nature and properties of minesoils it is essential to be aware of and manage early soil development processes.

Traditionally soil development was understood to result from five factors including climate, organisms, parent material, relief, and time. The influence of each of these factors on initial soil development of minesoils is discussed. Techniques for managing minesoil development are reviewed.

INTRODUCTION

Strippable coal deposits underlay more than 3 million hectares of land in the Northern Great Plains of the U.S. and Canada. Mining for precious metals; uranium; sand and gravel; and bentonite, disturbs more acreage than for coal mining. The cumulative effect of mining could significantly alter our nations soil resources, as has occurred in many parts of Appalachia.

Soils throughout the Northern Tier of the United States and Prairie Provinces have "evolved" or developed in response to a complex interaction of factors over the last 10 to 15 thousand years (post-Wisconsin time). Mining interrupts these soil forming processes and resets the pedologic clock to zero. Two legitimate concerns arise as a result: 1) soil properties which have taken thousands of years to develop will be destroyed-resulting in permanent reduction in soil productivity for thousands of years or 2) soil development after mining may progress in a different direction than in the past resulting in less productive soils than those found before mining.

[1] Soil Scientist, Cooperative Extension Service
Montana State University, Bozeman, Montana 59717-0003

The first concern can be quickly dispelled in that few studies have documented a direct relationship between increasing soil age and increased productivity. Often, in fact, the inverse is true. The second premise, that soil development may progress differently than before mining, is the subject of this paper. Previous studies have found that minesoils can develop along different pathways than those followed by natural soils. The result can be minesoils either more or less productive than those found before mining. Basic concepts of soil development will be outlined, and a framework for managing post-mine soil development will be discussed.

THEORY OF SOIL DEVELOPMENT

The first formal theory of soil development was developed by Jenny (1941,1980), although factors of soil formation were identified by the earliest workers in the emerging field of soil science in the 1880's. As stated by Jenny, the properties of soil and the kinds, thickness, and arrangement of horizons is determined by five soil-forming factors.

$$S = f(cl,o,p,r,t)$$

where

S = soil

cl = climate

o = organisms, or biola

p = parent material

r = relief

t = time

Many workers assumed that each factor had a separate influence on soil and devised studies to evaluate the influence of variations in a single factor with all others held constant (Birkeland, 1974). The terms climosequence, lithosequence, toposequence or catena, and chronosequence refer to a group of soils varying in climate, parent material, topography, and age respectively.

Other workers have proposed different approaches to the study of soil development. The independent influence of a single soil-forming factor is often difficult to isolate in nature. Hole and Nielsen (1970) suggest that the "factors" combine and interact to produce general "processes" of soil formation (Simonson, 1959). These processes acting through time on a newly-forming soil produce distinct properties. For example, the process of "melanization" produces a thick, dark "A" horizon high in organic matter content. Likewise, the processes of eluviation and illuviation tend to remove soluble salts and $CaCO_3$ from the upper profile and produce distinct layers of these materials deep in the profile.

A generalized model of soil development is shown (Fig. 1). This model incorporates concepts of the five soil-forming factors but also recognizes the interactions between factors and the unique influence of time. Without passage of time other soil-forming factors except parent material would not have an opportunity to act. Time in the model presented can be envisioned as the number of cycles the system has undergone.

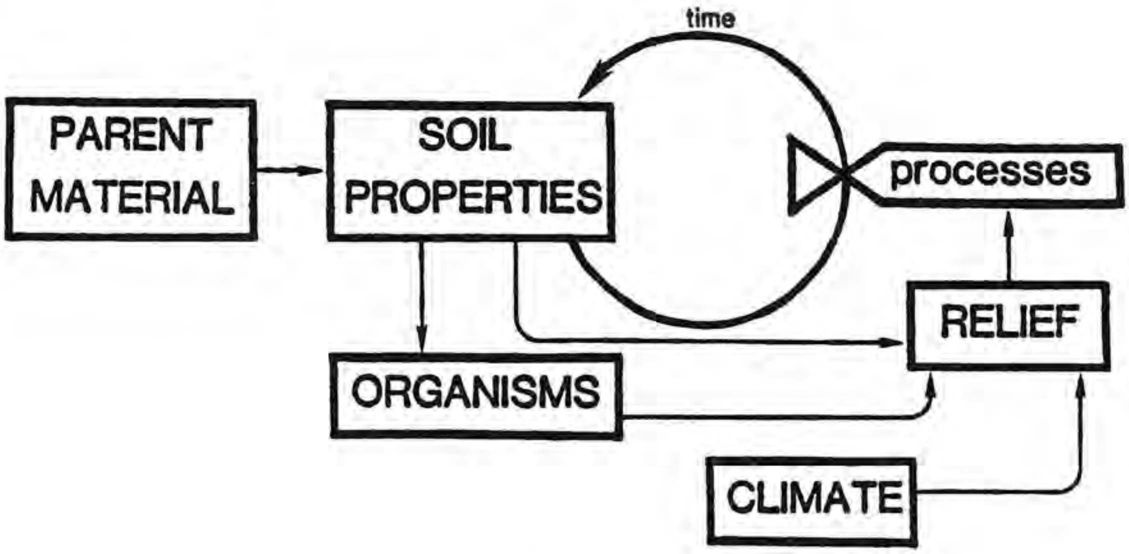


Figure 1. Conceptual model of soil development including soil-forming factors and processes of soil formation.

PARENT MATERIAL

Yaalon (1975) pointed out that the influence of parent material is diminished with the passage of time. However, parent material exerts a strong, in fact overriding, influence on soil properties in the early stages of soil development. As such, the parent material factor in minesoils, which is ultimately controlled by the reclamation process, plays an important role in controlling minesoil development processes.

RELIEF

The relief factor is very different in concept than the remaining factors of climate and organisms which control the input and flux of energy within the soil system (Huggett, 1975). The relief factor serves only to redistribute energy within the landscape.

The unique and perplexing role of relief in soil development is illustrated by both the 1938 soil classification as well as the Soil Taxonomy. Soils in footslope landscape positions which receive an inordinate influx of material are termed pachic or cumulic. Soils in particularly erodible positions (crest, shoulder) are azonal.

Huggett (1975) proposed that the basic unit of soil study should be the soil-landscape rather than the pedon, thus removing the relief factor from the soil-forming model and incorporating it as a characteristic of the soil-landscape unit.

CLIMATE

Climate is perhaps the only truly independent variable in the soil development model. The climate factor governs the quantity and timing of water input as well as the thermal energy of the soil system. Climate exerts a strong influence on soil development; one that cannot be altered by man.

ORGANISMS

The soil-vegetation system has many complex interrelationships causing some workers (Crocker, 1967) to defy separating them. As such, an opportunity to manage or alter soil development is afforded reclamation specialists through their selection of vegetation. In addition, floristic diversity and productivity can be readily influenced by soil reconstruction.

EXAMPLES OF SOIL DEVELOPMENT

CLASSICAL STUDIES

Initial stages of soil development have been studied on dune deposits (Salisbury, 1925; Jenny and others, 1969; Olson, 1958), Mt. Shasta mud flows (Dickson and Crocker, 1953a, 1953b, 1954) and glacial till (Crocker and Major, 1955). All workers found that vegetation strongly influences initial soil development. Yaalon (1975) emphasized the importance of parent material in determining the properties and genesis of young soils.

Dickson and Crocker (1953a, 1953b, 1954) studied soil development and vegetation succession on Mt. Shasta mudflows from 27 to 1200 years old. Organic carbon, total nitrogen, pH, and bulk density changed rapidly during initial soil development and were strongly influenced by vegetation. Total organic carbon and nitrogen in the soil and litter increased to a maximum in 200 years. A gradual flux of total C and N progressed from litter to soil for 500 years. Bulk density, pH, organic carbon, and N approached "steady state" (Birkeland, 1974) levels in the soil in 200 to 500 years. A similar pattern of soil development was found in recent glacial till in Alaska (Crocker and Major, 1955), and in northern California sand dunes (Crocker, 1967).

Olson (1958) studied soil development on a sequence of Lake Michigan sand dunes 0 - 12,000 years old. Organic carbon and nitrogen in the upper 10 cm rose quickly in the first 300 years, and more slowly until steady state was approached in 1,000 years. $CaCO_3$ was leached to 2 m in depth after 6,000 years. Silt and clay content rose from near zero initially to an equilibrium level in 1,000 years.

Parsons and others (1962) investigated soils on Indian mounds of known age in Iowa. He compared relative profile development of 1,000 to 2,000-year-old mound soils to undisturbed soils on 14,000 year old loess. Horizonation developed most rapidly in the first 1,000 years of soil development. "A1" horizons reached maximum expression in 1,000 years, while 2,500 years were required for pronounced soil structure to form and clay translocation to become evident. Bilzi and Ciolkosz (1977) found cambic horizons in 200-year-old alluvium and 40-year-old minesoils (Ciolkosz and others, 1977) in Pennsylvania. They reported that 2,000 years were required for argillic horizon formation in Oregon while more than 5,000 years were required in New Mexico.

The general pattern of soil development is for levels of properties to change quickly during initial stages then change less rapidly as equilibrium is approached. The amount of time required to reach equilibrium is different for each property. Organic matter, pH, and total nitrogen can change quickly in soils (100-500 years). Carbonate movement requires more time (1,000 years), while clay movement may require 2,000 to 10,000.

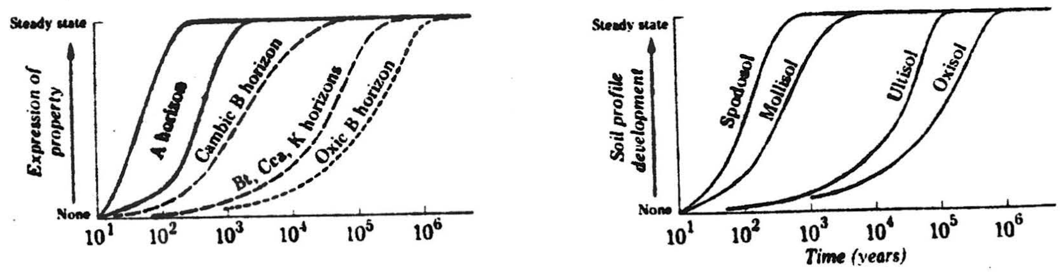


Figure 2. Changes in soil properties and development over time (from Birkeland, 1974).

MINESOIL GENESIS

Smith and others (1971) studied soil genesis in iron-mine spoils in West Virginia. Spoils had deeper rooting, higher cation exchange capacity, and higher exchangeable nutrients than natural soils. Natural soils had lower bulk density, higher porosity, stronger soil structure, and higher nitrogen and organic carbon contents. Water regimes in the top two feet were similar in spoils but natural soils had higher infiltration rates. The authors concluded that minesoils were superior to natural soils in some respects while inferior in others. The minesoils were expected to support woodland and pasture as productive as on unmined soils.

Wali and Freeman (1973) studied species composition and soil characteristics of North Dakota mine spoils compared to adjacent undisturbed areas. Spoils had higher pH; electrical conductivity; exchangeable magnesium, and sodium; total phosphorus, and sulfur; and silt, and clay content. Unmined sites had more organic carbon; exchangeable potassium; species diversity, abundance, and density. Some mined sites did not support "desirable" plant species 53 years after mining.

Caspall (1975) found that organic matter content increases rapidly with surface material and decreased from topsoil to spoil to compacted spoil.

Anderson (1977) conducted a study of 28-to-40-year old minesoils in Saskatchewan derived from glacial till. Soluble salts were leached below 50 cm where large amounts of carbon and nitrogen had accumulated. Humus composition in 28-year old minesoils was similar to that in natural soils.

Schafer and others (1980) compared minesoils from 1 to 50 years old in southeastern Montana to adjacent natural soils (Fig. 3). Organic C content from 0-10 cm soil depth reached levels found in natural soils within 30 years, but would not reach equilibrium at 20-50 cm for 400 years or more. Litter accumulation was common under pioneer vegetation on minesoils resulting in wide C/N ratios; reduction in available N; successional stagnation; and reduced plant community production. Soluble salts were leached downward in minesoils in tens of years, but thousands of years would be required for carbonate removal to occur in the upper 50 cm. Soil structure developed more quickly near the soil surface (10-50 years) than below 10 cm (50-200 years), and was attained sooner in clayey than in sandy minesoils. Many characteristics of minesoils were expected to always be different from natural soils. Well-designed minesoils were highly productive, in a few cases exceeding the potential of natural soils.

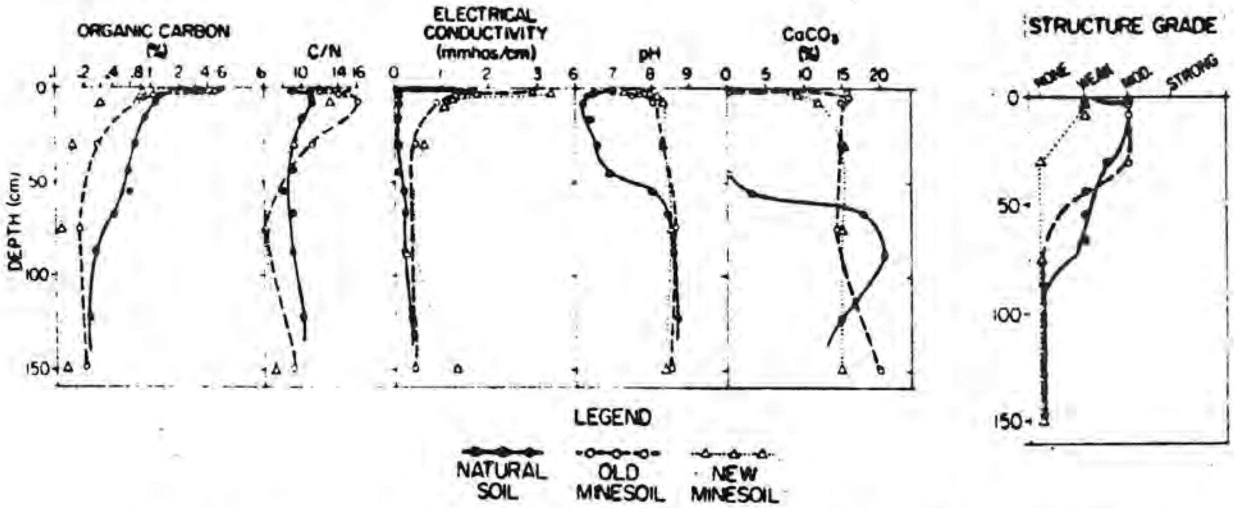


Figure 3. Soil properties of natural soils, five, and 50-year old minesoils (from Schafer and others, 1980.)

In most of the studies discussed above soil genesis in minesoils followed a pathway similar to that followed by natural soils so that minesoil properties would become similar to natural soils in 100 to 10,000 years. Nielson and Peterson (1972) discussed the soil development of minesoils in Utah tailings. Oxidation of pyrite caused pH to decline from eight after deposition to a pH of four after four years and pH less than two in 20 years. Thus, the presence of sulfides caused these minesoils to become far different than natural soils.

Merrill and others (1980) discussed the chemistry of North Dakota minesoils high in subsoil sodium. Working with smectite-rich clay and clay loam spoils, they found that sodium migrated upward into topsoil layers after three to six years, thus reducing hydraulic conductivity and making the effective rooting depth shallower. Dollhopf and others (1980) found no upward flux of sodium in illitic clay loam materials suggesting that subsoil texture and clay mineralogy influence sodium migration. Results from these studies illustrate the importance of parent material chemical and physical properties on influencing post-mine soil development.

MANAGING MINESOIL DEVELOPMENT

A review of minesoil development studies indicates that most soils on mined land become more similar to natural soils with increasing age. Despite these trends, however, minesoils can be either more or less productive than natural soils.

In some disturbed lands, soil development may progress along a different pathway than for natural soils, often leading to non-productive extremes. This is especially true where chemically inimical parent materials are used such as those high in soluble salts, sodium, or sulfides.

It follows that the reclamation specialist should be aware of the influence of soil development factors on minesoils and should so manage those factors to achieve desired goals. The concept of managing soil forming factors is especially foreign because the opportunity to change soil relief, or parent material is seldom afforded except in disturbed land reclamation.

PARENT MATERIAL

As has been discussed, the parent material factor is very important in early stages of soil development. At least three techniques are available for managing the parent material used to construct minesoils. They are soil reconstruction, selective overburden placement, and addition of soil amendments.

Soil reconstruction involves selection, handling, mixing, and placement of soil and overburden materials in the optimum sequence and location so that reclamation objectives are met. Guides have been published for ranking cover-soil quality (Schafer,1979), but soil reconstruction in fact entails more art than science.

Selective overburden placement uses pre-mine overburden data and selective overburden handling techniques such as mixing, burial, or capping, to insure that unsuitable materials are isolated from the reclaimed minesoil by six feet or more of better quality material. Dollhopf and others (1981) have discussed the data requirements, costs, and logistics of selective overburden placement.

Soil amendments can be used to modify the chemical characteristics of minesoil parent material. Gypsum or sulfur can be added to counteract a sodium problem; lime can correct for potential acid production; and fertilizer, manure, or sludge can supplement the plant nutrient status of the minesoil. Soil amendments should be seen as an integral rather than a supplemental part of the reclamation process, as they can have long-term effects on soil chemistry, soil physical properties, erosion, vegetative productivity, and plant community development.

ORGANISMS

Soil and the vegetation it supports are closely related and as such the design of post-mine vegetation and soil systems should go hand in hand. Under ideal conditions, complimentary soil and vegetation are mutually beneficial. When soils are capable of supporting productive stands of vegetation, soil organic matter can accumulate quickly which in turn promotes even greater production.

Vegetation and microorganisms play a major role in soil organic matter accumulation and nutrient cycling. They can also influence the water regime of soils which can in turn affect soil chemistry. There is evidence for example, that revegetation of sulfide-rich tailings in arid regimes may slow acid production in the root zone by removing water during the periods of peak microbial activity (summer).

RELIEF

The final contour of a mine is often controlled solely by the mine engineering staff and is not influenced by the reclamation staff. The soil development model suggests the critical role of relief in the minesoil formation process. Moran and others (1978) suggest that post-mine geomorphology affects not only soil development but also erosion; surface water, and ground water quality and quantity. Design of post-mine geomorphology must take into account soil stability, the hydrologic system, the unconsolidated nature of the spoil, overburden swell factor, overburden to coal ratio, and relationship to the surrounding landscape. Clearly, the reclamation staff must have input into post-mine contour considerations.

Design of the post-mine geomorphology is one of the most challenging aspects of disturbed land reclamation and can also influence cost more than other facet of reclamation. Many recent developments in reclamation technology have come about as a result of increasing attention being focused on geomorphology (Stiller and others, 1980).

Many mines now design complex slopes where convex or flat slopes were once common due to their lower costs. Drainages in reclaimed areas are designed with smooth, concave profiles because the erosive influence of knickpoints is recognized. Highwall reduction remains an important issue because when highwall slope is reduced to control erosion, slope length increases which adds to erosion.

CHECKLIST

The framework proposed for soil management in reclaimed systems has five steps which should incorporate many of the principles outlined in this paper (Figure 4.).

Figure 4. Framework for soil reclamation and management in a mining operation.

The first step is to set appropriate land use goals. A suitable soil for range forage production would be different than one for shrub and tree reestablishment or irrigated agriculture. Next an inventory of soil and overburden materials should be made. Potentially unsuitable soil parent materials which could lead to acidification, upward sodium movement or other undesirable soil development processes should be identified.

A landscape plan must be developed which simultaneously meets constraints of soil and hydrologic stability, water quality and quantity, and mining production costs. Next a complimentary soil and vegetation plan should be designed within the context of the landscape plan. If at this point in the planning process it appears that land use or other goals cannot be met, then revision of the landscape and soil plan using a different set of constraints may be necessary.

Finally, after completion of mine and reclamation plans (and approval by regulatory agencies), minesoils must be properly managed to insure continued fulfillment of planning goals. Post-mine management may include grazing, harvest, fertilization, liming, controlled burning, supplemental irrigation and a host of other measures.

Application of these principles though complex, will assure that the best possible job has been done in building productive, and stable post-mine landscape-soil-vegetative ecosystems.

LITERATURE CITED

1. Anderson, D.W. 1977. Early stages of soil formation on glacial till mine spoils in a semi-arid climate. Geoderma 19:11-19.

2. Bilzi, A.F. and E.J. Ciolkosz. 1977. Time as a factor in the genesis of four soils developed in recent alluvium in Pennsylvania. Soil Sci. Soc. of Amer. J. 41:122-127.

3. Birkeland,P.W. 1974. Pedology,Weathering, and Geomorphological Research. Oxford Univ. Press. Toronto. 285 p.

4. Caspall, F.C. 1975. Soil development on surface mine spoils in western Illinois. p. 221-228. IN Third Symposium on Surface Mining and Reclamation. NCA/BCR.

5. Ciolkosz, E.J., R.L. Cunningham, and G.W. Peterson. 1977. Characteristics and properties of Pennsylvania minesoils. p. 168. 1977. Agron. Abstr. Soil Sci. Soc. Amer. Annual Meeting, Los Angeles.

6. ____________ 1967. The plant factor in soil formation. p. 179-190. IN Selected Papers in Soil Formation and Classification. Soil Sci. Soc. Amer. Special Publ. 1. Madison, Wisc.

7. ____________ and J. Major. 1955. Soil Development in relation to vegetation and surface age at Glacier Bay Alaska. Ecol. 43:427-448.

8. Dickson, B.A. and R.L. Crocker. 1953a. A chronosequence of soils and vegetation near Mt. Shasta, Ca. I: Definition of the ecosystem investigated and features of plant succession. J. Soil Sci. 4:124-141.

9. ____________ and ____________ 1953b. A chronosequence of soils and vegetation near Mt. Shasta, California. II: Development of the forest floors and the C and N profiles of the soils. J. Soil Sci. 4:142-154.

10. ____________ and ____________ 1954. A chronosequence of soils and vegetation near Mt. Shasta, California. III: Properties of the mineral soils. J. Soil Sci. 5:173-191.

11. Dollhopf, D.J., E.J. Depuit, and M.G. Klages. 1980. Chemical amendment and irrigation effects on sodium migration and vegetation characteristics in sodic minesoils in Montana. Mont. Agr. Expt. Sta. Bulletin. 736. 109p.

12. ______________ J.D. Goering, C.J. Levine, B.J. Bauman, D.W. Hedburg, and R.L. Hodder. 1981. Selective placement of strip mine overburden in Montana. Final report to the U.S. Bureau of Mines. 195p.

13. Hole, F.D. and G.A. Nielson. 1970. Soil genesis under prairie. IN Prairie and Prairie Restoration. Biol. Field Stat. Spec. Publ. 3. Galesburg, Ill.

14. Huggett, R.J. 1975. Soil landscape systems: a model of soil genesis. Geoderma. 13:1-22.

15. Jenny, H. 1941. Factors of Soil Formation. McGraw-Hill, N.Y. 281 p.

16. ________ 1980. The Soil Resource. Springler-Verlag. Berlin. 377p.

17. ________ and R.J. Arkely, and A.M. Schults. 1969. The pygmy forest podzol ecosystem and its dune associates of Mendocino Coast. Madrono. 20:60-75.

18. Merrill, S.D., F.M. Sandoval, J.F. Power and E.J. Doering. 1980. Salinity and sodicity factors affecting suitability of materials for mined-land reclamation. IN Adequate Reclamation of Mined Lands? Symposium Proceedings. p. 3-1 to 3-25. Soil Conservation Society of America, Billings, MT.

19. Moran, S.R., G.H. Groenwald, and J.A. Cherry. 1978. Geologic, hydrologic, and geochemical concepts and techniques in overburden characterization for mined-land reclamation. North Dakota Geol. Surv. Rept. Inv. 63.

20. Nielson, R.F. and H.B. Peterson. 1972. Treatment of Mine Tailings to Promote Vegetative Stabilization. AES Utah State University. Logan, Utah. Bulletin 485.

21. Olson, J.S. 1958. Rates of succession and soil changes on southern Lake Michigan sand dunes. Bot. Gaz. 119:125-170.

22. Parsons, R.B., W.H. Scholtes, and F.F. Riechen. 1962. Soils of Indian mounds in northeastern Iowa as benchmarks for studies of soil science. Soil Sci. Soc. Amer. Proc.

23. Salisbury, E.J. 1925. Note on the edaphic succession in some dune soils with special reference to the time factor. J. of Ecol. 13:322-328.

24. Schafer, W.M. 1979. Guides for estimating cover-soil quality and mine soil capability for use in coal strip mine reclamation in the western U.S. Reclamation Review 2:67-74.

25. __________ and G.A. Nielson, and W.D. Nettleton. 1980. Minesoil Genesis and Morphology in a Spoil Chronosequence in Montana. Soil Sci. Soc. Amer. J. 44:802-807.

26. Simonson, Roy W. 1959. Outline of a generalized theory of soil genesis. Soil Sci. Soc. Amer. Proc. 23:152-156.

27. Smith, R.M., E.H. Tyron, and E.H. Tyner. 1971. Soil development on mine spoil. West Virginia Agr. Expt. Sta. Bulletin 604T.

28. Stiller, D.M., G.L. Zimpfer and M. Bishop. 1980. Application of geomorphic principlestosurfacemine reclamation the semi-arid west. J. Soil and Water Cons. 35:274-277.

29. Wali, M.K., and P.G. Freeman. 1973. Ecology of some mined areas in North Dakota. IN some environmental aspects of stripmining in North Dakota. ed. by M.K. Wali. N.D. Geological Survey educ. series 5.

30. Yaalon, D.H. 1975. Conceptual models in pedogenesis: Can soil-forming functions be solved? Geoderma 14:180-205.

Reclamation monitoring: The critical elements of a reclamation monitoring program in western North America. R.L. Johnson, Alberta Environmental Centre, P.J. Burton, University of Illinois, V. Klaassen, Monenco Consultants Limited, P.D. Lulman, TransAlta Utilities Corporation, D. Doram, TransAlta Utilities Corporation.

The potential for serious environmental impacts resulting from large scale surface mining is proportional to the difficulty of reclaiming the disturbed area. Reclamation monitoring programs are designed to measure the extent of environmental disturbance and the rate of recovery. This paper lays out a methodology for selecting, measuring, and interpreting critical elements of a reclamation monitoring program. The end land use is employed as a decision making key to identify the major factors affecting reclamation monitoring and to select the biophysical and economic characteristics requiring measurement. The latter portion of the paper explores the ways of optimizing the efficiency of monitoring programs. It outlines the relative advantages and weaknesses of several sampling designs commonly used in reclamation monitoring.

INTRODUCTION

Surface mine reclamation monitoring attempts to measure the extent of environmental change due to mining activities and the rate of recovery. More specifically, monitoring programs have one or more of the following objectives (Wilkey et al. 1980):

- to provide an overall assessment of the reclamation effort in order to determine its operational effectiveness;
- to develop, demonstrate, and evaluate the needed technologies for future reclamation efforts;
- to address the potential environmental problems that may develop at the mining site; and
- to provide economic assessment necessary to transfer the most cost effective reclamation techniques to future projects.

The achievement of all of these objectives depends on the selection of parameters to be monitored. Common difficulties in the selection of monitoring variables are (1) choosing the most environmentally 'critical' properties and (2) choosing properties which have little natural fluctuation and yet are ecologically or economically interpretable (Ward 1978). For terrestial systems there are few guidelines for parameter selection and no format for the design of monitoring programs.

This paper employs end land use to define the context of reclamation objectives and thereby lay out the precepts of monitoring programs. The selection of specific monitoring variables is predicated on understanding the underlying principles of soil and vegetation development in relation to the post-mining landscape. Finally, we concern ourselves with the design and implementation of a sampling program for reclamation monitoring and the interpretation of the collected results.

LAND USE CONSIDERATIONS IN RECLAMATION MONITORING

Land uses prior to disturbance in proposed mining areas are agriculture, wildlife habitat, forestry and recreation. Potential uses, after mining, are determined by the biophysical environment - soils, climate, water and vegetation - and by the effect of mining and reclamation on the environment. Economic factors, especially when agriculture or forestry is the designated land use, can also be important. Ideally, the end result of reclamation is a landscape where all potential uses, limited only by the environmental and economical restraints, are possible.

Table 1 outlines the major land uses, the dominant factors affecting the choice of land use, and the properties and processes which should be monitored to guage the success of the reclamation program. Although it is not made explicit in Table 1, a well structured program of reclamation monitoring starts prior to mining, and therefore prior to reclamation, in order to establish the baseline conditions of land productivity and stability.

Agriculture Land Use

The factors affecting the planning and use of agricultural land are soils, crops, climate, and economics. The collection of information prior to disturbance should follow standard procedures for soil and crop surveys. Materials handling for reclamation may mean that more detailed scales of surveys need be conducted than those presently available. Also the components of crop productivity (interrelationship of yield, quality, and management) can often be assessed only when site specific information is available. Economic information is often available from published sources like the Alberta Agriculture Consensus of Costs and Return data. Climatic data is important because reclamation conditions may offer new crop production possibilities which must be evaluated for their climatic adaptation.

The objectives of reclamation monitoring follow from the overall goal of establishing land capabilities, crop productivities, and reasonable management costs, similar to those that existed before mining.

TABLE 1

End Land Use Considerations for Reclamation Monitoring

End Land Use	Dominant Influencing Factors	Factors and Processes Monitored
Agriculture	Vegetation	Cropping pattern, productivity, % cover.
	Soils	Soil fertility, chemistry, water, structure.
	Climate	Precipitation, evapotranspiration, temperature.
	Cost-Benefit	Capital investment, capital returns.
Wildlife	Species	Species diversity, numbers, area required for habitat.
	Vegetation	Diversity, % cover, palatability, succession.
	Soils	Landscape, toxic elements.
	Water	Quantity, quality of surface reserves.
Forestry	Vegetation	Establishment, productivity.
	Soils	Soil quality and site index.
	Water	Surface water.
	Cost-Benefit	Capital investments, capital returns.
Recreation	Vegetation	Species diversity, % cover.
	Soils	Landscape, soil mechanics.
	Water	Type (rivers, lakes, etc.) quantity and quality of surface reserves.

Wildlife Land Use

There are no government guidelines in Alberta dealing with areas to be returned to wildlife use, but two logical objectives follow from any consideration of wildlife habitat:

1. Successful habitation of a reclaimed area by the same or similar wildlife species present on pre-mined lands.
2. Development of a diverse, self-sustaining ecosystem which favours the proliferation of the desired wildlife species and does not require maintenance.

The components required in a monitoring program for wildlife habitat reclamation are conveniently broken into one pre-disturbance and three post-disturbance stages (Table 2). The need for information collected prior to disturbance is often met in formulating an environmental impact assessment, but reclamation monitoring after mining must concentrate on the interrelationship of wildlife species, vegetative production and diversity, and the availability and the quality of water. It is evident that topography and soils will affect these relationships directly but are secondary in a monitoring program to considerations of food, water, and shelter to the wildlife populations.

Forestry Land Use

The decision to use disturbed land for purposes of commercial forestry implies two objectives: (1) maximizing sustained yield of timber and (2) minimizing cost and time of timber production. The maximization of forest site quality - a concept translate into topographical, soil and vegetation variables by means of "site index" -

TABLE 2

Monitoring Reclamation Progress of Wildlife Habitat

Pre-Mine Environmental Conditions	Phase of Reclamation Program: Initiation	Evaluation	Stabilization
- on area to be mined and a control area - wildlife - vegetation & climate - topography & landscape - soils - water	- re-construct topography and landscape - soil replacement with possible ameliorations - revegetation (erosion control, productivity, diversity) - water (location, quality)	- wildlife - species and number using reclaimed area in comparison to a control area (spatial and diversity basis) - vegetation - growth rate analysis, community diversity by quantity index, turnover of plant communities (succession), use by wildlife as food and cover, etc.	- use of reclaimed area by similar species and numbers of wildlife as found on control area - diversity and productivity of plant community comparible to original community - similar to original or control vegetation with the ability to maintain itself (ecological stability)

is the most logical basis for achieving an acceptable level of productivity and minimizing long-term inputs. Since the measurement of site index, prior to disturbance, results in the identification of the critical environmental factors governing forest productivity, operational reclamation can design a landscape which optimizes site quality.

Reclamation programs and post reclamation monitoring will then use standard reforestation strategies to make optimal use of reclaimed areas. The choice of tree species, the density of tree establishment, and the eventual measurement of site index on reclaimed lands are the three components of value to the commercial forestry monitoring program.

Recreation Land Use

The designation of a reclaimed area to recreation land use means that topography, vegetation, soils, and water will be primary factors under consideration. Recreation is a broad term encompassing a wide range of possible activities, and the choice of monitoring variables can only be made after specific decisions are made about the recreational priorities. However, the mixture of trees, shrubs, forbs, and grasses should provide for a variety of uses. Soil properties of specific interest to recreation planning and implementation are compactibility and drainage. The quantity and quality of surface and groundwater are also attributes which will be influenced directly by recreational activities.

BIOPHYSICAL COMPONENTS OF RECLAMATION MONITORING

The most important and most difficult step in the design of monitoring programs is the selection of parameters, because reclamation progress is judged successful or unsuccessful by the quantity and rate of change which is measured. The difficulty lies in the selection of the best indicators of ecological recovery and ensuring that the measurements are practical and interpretable.

This paper limits itself to a consideration of two components of a terrestial monitoring program - vegetation and soil - and uses the underlying principles of vegetation and soil development in post-mining landscapes to identify the critical parameters of reclamation monitoring. The processes most important to the evaluation of stable plant and soil systems on western North America are:

- plant growth and succession;
- effects of vegetation on soil genesis;
- water balance;
- soil tilth and compaction;
- soil salinity and sodicity; and
- soil nutrient accumulation and supply.

Plant Growth and Succession

The status of the vegetation is indicative of and often determines the status of reclamation as a whole. The methods used for monitoring must be designed such that they are responsive to the processes of plant establishment, plant growth, and community stability. The productivity of planted species is important for assessing agriculture and forestry potential; the successional status of native plant communities is critical to the establishment of wildlife habitat and recreational areas. The success of planted species, the long-term processes of invasion by other plants, turnover in species composition, and community succession must be evaluated in terms of survivial, cover, and productivity.

Land reclamation programs generally include revegetation activities designed to establish a specific plant cover. Seeding and transplanting methods are used to establish monocultures or species mixtures for the purposes of erosion control, to assist in soil development, and to return the land surface to a productive use. The success exhibited by the introduced plants is an item of primary interest in assessing the reclamation status of a management area and hence in redesigning and improving future revegetation programs. The processes and conditions critical to defining the success of vegetation managed for production purposes are: germination and emergence, biomass productivity, plant vigour and survival, and longevity.

It is just as important to consider the long-term dynamics of a newly planted vegetative community as it is to determine the success achieved in establishing and growing introduced plants. These are some of the questions relevant to reclamation planning that the monitoring of plant community dynamics can address:

- How long can a seeded plant cover remain viable and productive?
- Which species of native plants invade a revegetated area of minespoil over time?

- Are invading species noxious weeds or are they amenable to future land uses and the improvement of soil quality?
- At what stage do plant community changes decelerate or become unimportant, and how long does it take to reach such a stage?
- How can natural community changes be managed or enhanced to achieve a desired land use at least expense?

The mechanisms of succession as first interpreted by Clements (1916) still provide a useful framework for the analysis and discussion of successional phenomena and the factors which are thought to govern such phenomena:

- exposure or deposition of a new substrate;
- invasion, either by sprouting of plant parts already present, or by the immigration of disseminules from surrounding areas;
- excesis, or stand development, referring to the germination, establishment, growth, and reproduction of the biota;
- competition among the plant individuals and populations, thereby modifying the development process;
- site or habitat modification resulting from the presence of plants and animals, further influencing the success of existing populations and the establishment of future species; and
- final stabilization of species composition.

The study of plant community dynamics and long-term succession can be difficult. The key aspect of the successional process is the change in plant populations. Vegetational changes are often so slow that they are very difficult to detect and measure, especially in later stages of succession.

Effects of Vegetation on Soil Genesis

The manipulation of vegetation types in relation to different parent material is critical to achieving full reclamation potential (Curry 1978). In a comparison of minesoil development in Montana covering 50 years of reclamation, Schafer et al. (1979) show that modern techniques of overburden and soil classification coupled with contemporary practices of vegetation management are more effective in re-establishing productive grassland communities in five years than 50 years of natural succession on poor quality mine soil.

Water Balance

The most important physical property of soils governing the successful re-establishment of vegetation on surface mined land in Western Canada is water balance. Reclamation of semi-arid (250 to 500 mm precipitation per year) environments depends on the conservation and efficient utilization of a limited precipitation. Under these conditions infiltration, runoff, leaching, and evaporation must be controlled to maximize the root absorption of soil water and the dry matter production per unit of soil water used. The soil properties which have been shown to affect runoff erosion on mined lands are: texture, rock fragmentation, exchangeable sodium, bulk density, and clay type (Power et al. 1978).

Soil Tilth and Compaction

Surface mining and reclamation involve the use of heavy machinery for the excavation and replacement of large quantities of overburden and soil. Machine traffic can cause soil compation to a degree at which growth is impeded. Even though frost action and wetting and drying cycles (pedoturbation) will loosen most compacted zones near the surface, compacted layers below 50 centimeters can persist indefinitely. The soil properties that are measured to assess the extent and effect of compaction are: strength, structure, consistence, plasticity, aggregrate size and stability, and bulk density.

Soil Salinity and Sodicity

In surveying the problems of salt-affected soils in mined areas, Sandoval and Gould (1978) summarize their observations about the interactions of soil quality and soluble salts in these points:

- salinization is reversible and frequently controllable.
- sodic soils often show a lack of structural stability and a severely restricted infiltration rate, and therefore need special treatment for improvement and management.
- chloride(Cl^-) and sodium (Na^+) are most often the specific ions causing direct plant toxicity.
- when chloride or sodium is toxic boron (B) can accumulate in toxic amounts.
- calcium (Ca^{2+}) uptake by plants is often reduced in sodic salts as a result of sodium induced deficiencies.
- phosphorus solubilities increases with sodium domination of the soil exchange complex, but plant assimilation of phosphorus at high pH values is less than at neutral soil pH levels.

In the assessment of processes affecting mined lands which involve salinization and/or an increases in exchangeable sodium, the dynamics of salt and water flow are the primary determinants of the severity of deteriorating soil quality and should form the basis for prescribing remedial action. The most commonly monitored variables which can be interpreted for diagnostic or remedial purposes are: hydraulic conductivity, soluble cations and anions, saturation percent, exchangeable cations, cation exchange capacity, pH, and electrical conductivity. Calculations of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are valuable indices of cation relationships.

Soil Nutrient Accumulation and Supply

Soil fertility is of major importance in regulating plant growth on mined lands. The two primary components of soil fertility are organic matter content and cation exchange capacity. Reclamation can begin from a premise that soil science has shown to be valid: any practice which increases the production and protection of stable soil organic matter (humus) will enhance the quality of the soil environment. The humus acts as the reservoir of nutrient elements in soils; most of the soil nitrogen, phosphorus, and sulphur are contained in the organo-mineral complexes (Witkamp 1971). Furthermore, humus provides the soil with an increased surface area which enhances the exchange capacity; it acts as a glue in soil structure affecting both micro- and macrostructures; it decreases bulk density, thereby aiding infiltration and water percolation; and it increases water holding capacity (Allison 1973).

Cation exchange capacity is the capacity of the soil to hold cations and to exchange species of these ions in reversible chemical reactions. The two components of total cation exchange capacity in the soils - the mineral and organic colloids - are often imbalanced in developing soil profiles. The contribution of the mineral fraction is fixed by the kinds and amounts of clay minerals, and only intense weathering processes can affect it. The organic fraction, on the other hand, is a result of biological activity, in soil, and although it may make a negligible contribution in the beginning, the organic colloids can increase rapidly after initial vegetative colonization (Olson 1958, Chandler 1942).

Essential nutrients are divided somewhat arbitrarily into those required by the plant in large or small quantities. Nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium, are used in tens or hundreds of kilograms per hectare per year; and the micro-nutrients or trace elements may be used in kilograms or grams per hectare per year. The difference between total nutrient content and available nutrient levels in soil is great for nearly all elements. Therefore, it is often important to measure both pools in order to relate present availability to future demands and increases in pool size.

Overall, a reclamation monitoring program must reflect the vegetation and soil interactions expected under the environmental conditions prevalent in the plains and mountain areas of western North America. The critical measurements will depend upon land use, geology, and climate, but in nearly all cases some aspect of plant growth, plant community succession, water balance, soil tilth, salinity or sodicity, and soil fertility will be included (Table 3). The specific properties

TABLE 3

Critical Components and Related Properties of a Reclamation Monitoring Program in Western North America

Component	Properties
Plant Growth and Succession	Biomass productivity Cover Longevity
Effect of Vegetation on Soil Genesis	Organic matter accumulation Rooting depths
Water Balance	Infiltration Runoff Water holding capacity Hydraulic conductivity
Soil Tilth and Compaction	Soil strength Bulk density
Salinity and Sodicity	Saturation percent Soluble cations and anions Electrical conductivity Exchangeable cations and cation exchange capacity pH
Soil Nutrient Accumulation and Supply	texture pH total and available nitrogen carbon-nitrogen ratio Available phosphorus Available potassium Available sulphur

included in a monitoring program will reflect the special problems of soil, geology, and climate, the rate of plant community and soil development, and the level of understanding of undisturbed ecosystem interactions.

SAMPLING DESIGN AND STATISTICAL ANALYSIS

The evaluation of reclamation progress and success must be quantitative. A visual or subjective assessment of large areas of reclaimed land my be important to aesthetics and public acceptance of reclamation success, but qualitative assessments cannot answer many of the most important question which a monitoring program must address:

- Is productivity the same as it was before mining?
- Is productivity increasing and at what values will it level off?
- What soil nutrients are limiting and how much fertilizer should be applied?
- Is the ecosystem stable and self-maintaining?

Questions of this kind require numerical analytical data in order to be answered.

A consistent sampling program must be developed and followed which will give a representative description of the population or area under study. The first step is to define the population and choose a sampling design. The next step is to decide on the size of sample; in general, the larger the size, the more closely a sample is expected to represent a population. The choice of an appropriate sample size depends on the level of reliability desired, the variability of the population, and the cost of sampling.

Sample selection can be subjective, random or systematic. Subjective sampling requires that an individual, who is well acquainted with the material, choose samples which are considered representative. Such a procedure may be carried out where only a very few samples can be analyzed, and is completely dependent on the knowledge and skill of the sampler. Random sampling is usuallly superior to subjective methods of sample selection, because each unit of a population or an area has an equal probability of being chosen and there is a theoretical basis for the quantitative evaluation of a sample's quality or error. Probability theory can be applied and objective conclusions can be drawn. Systematic samples can be successfully representative if the even-spaced interval over which samples are selected has no relationship to any periodicity of the response being measured.

If a major objective of a study is to compare different subsets of a population, as well as to document the status of the whole population, or if the population or study area is very heterogeneous, stratified random sampling may be desireable. If separate random samples are selected from each natural or otherwise predetermined stratum (subset) of the population, population variance is decreased. Variance could alternatively be decreased by increasing the sample number in an unstratified random sample.

Although a number of different formulae can be used to determine the appropriate number of samples needed to represent a population, they reduce to a common form:

$$n = \frac{Z^2 \; S^2,}{e^2}$$

where	n	=	the number of samples required
	Z	=	standard normal deviate,
	S^2	=	variance, the square of standard deviation,
and	e	=	tolerable error or conficence limits, expressed in the units being measure.

If the original calculation of variance (S^2) is based on less than 60 samples, it is adviseable to substitute t^2 (from Student's tabulated t values) for Z^2.

Other statistical considerations which are important to reclamation monitoring are (1) the use of permanent plots in place of successive random sampling, (2) the methods of evaluating statistical significance of differences, and (3) the use of time series analysis or simulation modelling for predictive purposes. The advantages and disadvantages of permanent plot sampling have not been tabulated to date. Orloci (1978) and Wester (1977) have discussed the use of simple and multivariate analysis for evaluating changes in biophysical variables over space and times. The use of time series analysis and modelling has been fully reviewed by Pielou (1981) and Kessel (1980).

In summary, a reclamation monitoring program in western North America can be made most efficient and effective by considering a minimum of three stages:

1. A decision of land use to which the reclamation effort is directed.
2. An evaluation of biophysical components, including vegetation, soils, and climate, which influence the reestablishment of a stable plant community. The choice of specific monitoring variables, such as plant productivity, organic matter accumulation or exchangeable sodium percentage, will follow from the selection of critical components.
3. The design and implementation of an adequate sampling program to quantitatively measure the rate of change and degree of stability in vegetation and soils.

REFERENCES

Allison, F.E. 1973. Soil Organic Matter and its Role in Crop Production. Elsevier Sci. Publ. Col, New York.

Austin, M.P. 1977. Use of Ordination and Other Multivariate Descriptive Methods to Study Succession. Vegetation 35:165-175.

Chandler, R.F. 1942. The time required for podzol profile formation as evidenced by the Mendenhall glacial deposits near Juneau, Alaska. Proc. Soil Sci. Soc. Amer. 7:454-459.

Clements, F.E. 1916. Plant Succession: An Analysis of the Development of Vegetation. Carnegie Institute of Washington. Publ. 243. Washington, D.C. 512 pp.

Curry, R.R. 1978. Policy development to minimize mining impact: Report of the U.S. National Coal Policy Project. Pages 127-136. In: M.K. Wali (ed.). Ecology and Coal Resource Development. Vol. 1. Pergamon Press, New York.

Kessell, S.R. 1980. The Challenge of Modelling Post-disturbance Plant Succession. Environ. Manage. 5(1): 5- C.C. 12(7).

Mitchell, R.L. 1970. Crop Growth and Culture. Iowa State University Press, Ames, Iowa. 349 pp.

Olson, J.S. 1958. Rates of succession and soil changes on southern Lake Michigan sand dunes. Bot. Gaz. 119:125-170.

Orloci, L. 1978. Multivariate Analysis in Vegetation Research. 2nd Ed. Junk. The Hague.

Pielou, E.C. 1981. The usefulness of ecological models: A stocktaking. The Quarterly Review of Biology 56:17-31.

Power, J.F. 1978. Reclamation Research on Strip-Mined Lands in Dry Regions. In: F.W. Schaller and P. Sutton (eds.). Reclamation of Drastically Disturbed Lands. ASA, CSSA, SSSA. Madison.

Sandoval, F.M. and W.L. Gould. 1978. Improvement of saline and sodium affected disturbed lands. In: F.W. Schaller and P. Sutton (eds.). Reclamation of Drastically Disturbed Lands. Pp. 485-504. ASA, CSSA, SSSA. Madison, Wisconsin.

Schafer, W.J., G.A. Nielsen, D.J. Dollhopf, K. Temple. 1979. Soil genesis, hydrological properties, root characteristics and microbial activity of 1- to 50-year old strip mine spoils. Industrial Environmental Research Laboratory, U.S. EPA, Cincinnati, Ohio. 212 pp.

Ward, D.V. 1978. Biological Environmental Impact Studies: Theory and Methods. Academic Press. New York. 151 pp.

PLAINS HYDROLOGY AND RECLAMATION PROJECT:
RESULTS OF 5-YEAR'S OF STUDY

by

S. R. Moran[1], M. R. Trudell[1], A. Maslowski Schutze,[2]

A. E. Howard[1], T. M. Macyk[1] and E. I. Wallick[1]

ABSTRACT

The Plains Hydrology and Reclamation Project, an interdisciplinary study of rock-water interactions in reclaimed landscapes, completed five years of research in 1984. The geology, soils, hydrology, and hydrogeochemistry of two sites in the plains region of Alberta have been intensively studied both in unmined and reclaimed settings. Although project studies are continuing, several significant findings have emerged.

Large amounts of soluble salt are liberated in mined landscapes, primarily from pre-existing secondary salt in the soil zone but to a lesser extend from weathering of fresh overburden. Solution of this salt results in spoil water 3 to 7 times more saline than premining groundwater. Chemical equilibrium constraints related to the abundance of calcium preclude solution of all the available salt thereby preventing extremely high salinity but extending the period of time over which water of elevated salinity is present. Prediction of salinity and chemical composition of post-mining groundwater has become possible with considerable accuracy using aqueous extract data from overburden in conjunction with the chemical equilibrium model PHREEQE.

---

[1] Alberta Research Council, Terrain Sciences Department

[2] Alberta Research Council, Geological Survey Department

Spoil contaminated groundwater has been found in aquifers as much as 1.5 km from reclaimed areas. The only other significant offsite effect anticipated is the potential for soil salinization or saline seep development in favourable settings.

No evidence of soil salinization as a result of groundwater discharge has been found in reclaimed areas. Studies are continuing to assess the potential for salinization from surface ponding in depressions created by differential subsidence of the spoil and from shallow water table conditions. Management of post reclamation surface hydrology to minimize groundwater recharge appears the most promising approach to long-term prevention of salinization.

INTRODUCTION

As Alberta confronts the need for expanded development of coal resources in the coming decades, major concerns about the environmental impacts of mining and reclamation of mined areas remain unanswered. Most of the land that is underlain by minable coal in the plains area of the province is in agricultural production. Groundwater, which is commonly derived from coal beds, supplies nearly all the water needs of the region.

Reclamation research in Alberta and other parts of North America has concentrated largely on establishing soils and vegetation on graded overburden materials. Little work has focused on the long-term productivity of these reclaimed landscapes or on the long-term impacts of mining on water resources. Existing research and field experience in working mines suggest that in most places revegetation of graded, topsoil covered mine spoil is feasible. It is not clear whether salts liberated within the mine spoil will migrate into the replaced soil and degrade it or whether these salts will produce seriously degraded groundwater quality.

The objective of the Plains Hydrology and Reclamation Project is to develop a predictive framework that will permit projection of success for reclamation and impact of mining on water resources on a long term basis. Differences in physical and chemical properties of the pre-mining soils, overburden, and subsurface water will be used as keys to project postmining conditions. The predictive framework is to be based on an understanding of processes acting within the landscape so that in the future, mine sites that are not totally analogous to those that have been studied can be evaluated as well.

The project involves a holistic approach to reclamation by integration of studies of geology, hydrogeology, and soils, not only in a proposed mining area, but also in the adjoining unmined areas. This approach will permit the assessment of impacts and long term performance, not only in the mined areas, but also in the surrounding area.

During the first year of the proposed five year study, instrumentation to collect basic data on the geology, subsurface water, and soils of the Battle River mining area (Figure 1) was installed. Mapping of the soil and geology and a program of testhole drilling were also included in the initial phase of pre-mining site characterization. In spite of a late start during the first year, most of the instrumentation that was planned was installed but virtually no data could be collected.

During the second year (1980-81) approximately 90 percent of the instrumentation needed to characterize the Battle River site was completed. Monitoring programs that were begun in the very late stages of 1979-80 were continued throughout 1980-81. A considerable body of data on properties of overburden materials and chemistry and movement of subsurface water was accumulated by the end of 1980-81. In addition, experimental studies were initiated to describe the total salt yielding properties of various types of overburden materials under a range of conditions of water content and oxygen access.

During 1981-82, experimental studies on physical and chemical weathering of overburden materials at the Battle River site were carried out. Various physical and chemical properties of the overburden, such as grain size and mineralogy, were determined and were related to weathering characteristics.

Field studies were essentially completed to define hydrologic conditions at the Battle River site. Unanticipated complexities in flow patterns in spoil at Diplomat Mine, combined with problems with experimental techniques used to measure infiltration in spoil required further work on spoil hydrology at that site. Significant progress was made in the computer modeling of mine affected groundwater-flow systems (Schwartz et al., 1982). Study of post-mining groundwater supply potential was nearly completed and generalizable conclusions began. Preliminary synthesis of project data into a two component predictive model was possible. A group of hydrologic parameters that will permit projection of post-mining water-table configuration was identified and evaluation of their interactions had advanced well. The chemical component of the model had not advanced as far but the basic elements were identified.

During 1982-83, evaluation of a second site, the Highvale site (Figure 1), began with the installation of hydrologic monitoring instrumentation. Major effort focused on evaluation of hydrogeology and chemistry of mine spoil at both the Highvale and the Whitewood Mine. In addition, the existing network of wells installed by TransAlta Utilities to monitor groundwater in the unmined area adjacent to the Highvale Mine was expanded. A series of sites to monitor water movement in the unsaturated zone was installed. Initial study of the weathering characteristics of overburden was begun.

At the Battle River site new instrumentation was installed to refine our understanding of spoil hydrology and the flow of groundwater from the spoil into adjacent aquifers. Infiltration tests were successfully completed in the spoil and improved techniques of analysis greatly increased the amount of data that was derived from these and preceding tests. These data combined with groundwater data improved our understanding of groundwater recharge in the area. Overburden weathering studies were completed and a preliminary procedure to relate weathering data to groundwater chemistry in spoil was developed. Groundwater-flow modeling provided some significant insight into the spoil resaturation process (Schwartz and Crowe, 1984). Settlement of interridge areas following grading appears to facilitate infiltration of surface water, which promotes further settlement.

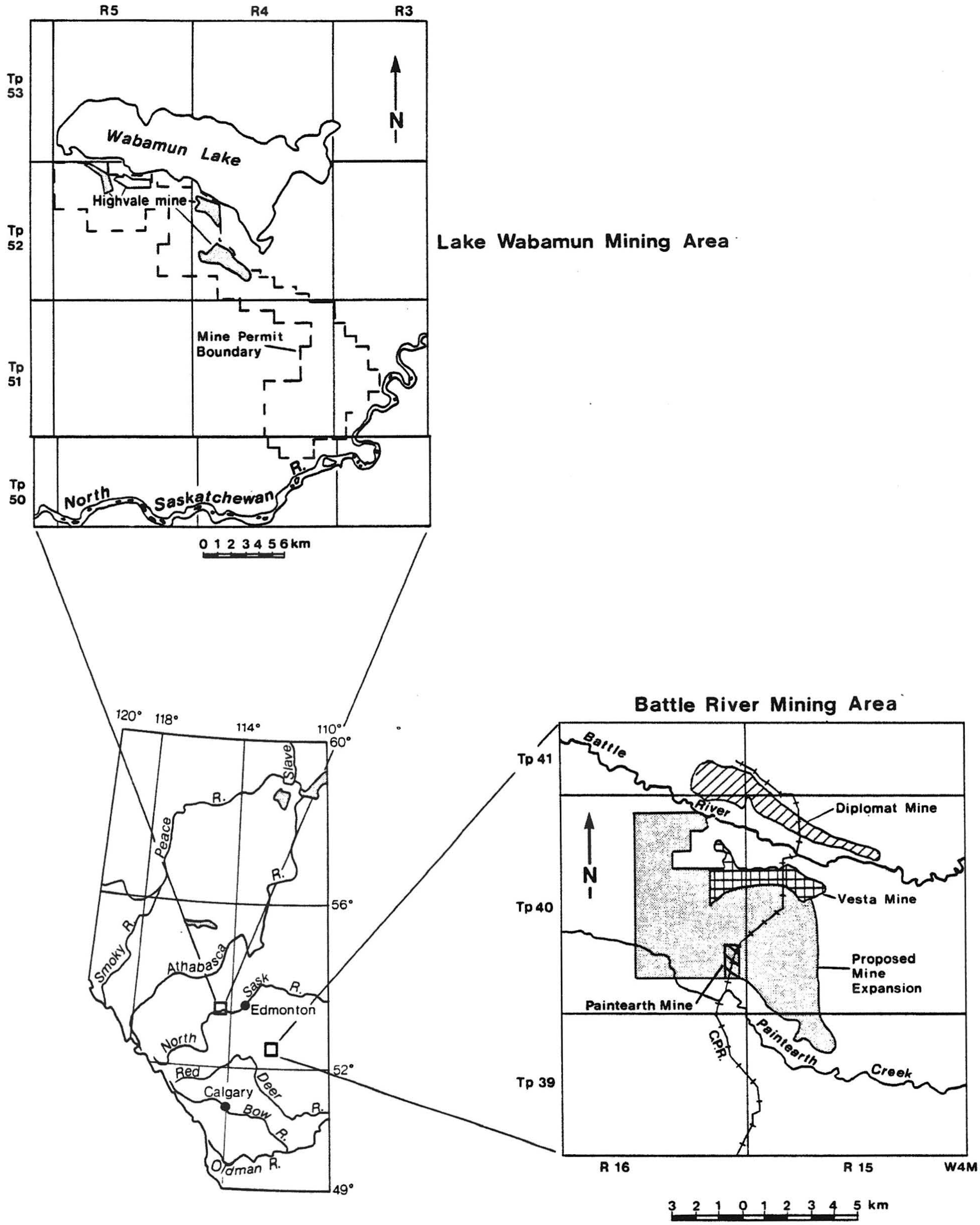


Figure 1. Location of PHRP study sites in the Battle River Mining Area and Lake Wabamun Mining Area, central Alberta

The fifth year of the study (1983-84) served as a period of refinement of the predictive framework developed at the Battle River site. At the Highvale Mine site instrumentation was completed and field scale experiments installed at both sites to test the validity of the overall predictive framework on salt yield of the overburden.

SUMMARY OF PROJECT RESULTS AND STATUS

The project is subdivided into two major objectives, which contain 5 and 3 subobjectives respectively. The following discussion is organized on the basis of these subobjectives.

OBJECTIVE A

To evaluate potential for reclamation of lands to be surface mined. The focus here is on features of landscape that make it productive in a broad sense not restricted to revegetation.

SUBOBJECTIVE A-1

To assess and evaluate the potential for long-term degradation of reclaimed "soils" through salt buildup.

The evaluation of long-term potential for salinization of reclaimed soils has involved (1) studies of the production of salt and (2) the transport of salt by groundwater. One of the major concerns that we had at the initiation of the study was that weathering of overburden materials, especially minerals containing sulfur in a reduced form, would lead to the long-term production of sulfate salts. Our research has established that, although considerable new salt can be released as a result of weathering of overburden materials, the processes are rapid and essentially complete soon after final regrading of the spoil surface (Wallick, 1983; Wallick et al., 1983). Although large amounts of salt are available from this weathering process and from salts already present in the overburden, especially in the lower part of the original soil zone, the release of this salt is limited by physical factors such as access to water and hydraulic conductivity of the spoil and by chemical saturation constraints. Regardless of the source of the salt, we find that groundwater in mine spoil is saturated with respect to calcite, dolomite, and gypsum (Trudell et al., 1983; Trudell and Moran, 1983). The factor that appears most critical in limiting salinity of spoil water is the availability of calcium over and above the level that can be consumed by ion exchange reactions.

We have found that the salt yielding properties of unmined overburden materials can be used as the basis for predicting the chemical makeup of groundwater in reclaimed mine spoil (Trudell et al. 1983; Trudell et al. 1984a; Trudell et al., 1984b). The predictive model allows the soluble salts in hypothetical 'spoil' material to dissolve in water based on a water: sediment ratio corresponding to field conditions. The aqueous geochemical model PHREEQE (Parkhurst et al., 1980) is utilized to account for mineral solubility limits particularly of calcite, dolomite and gypsum, partial pressures of CO_2 that are elevated relative to atmospheric levels, as well as ion exchange. The predictive model has been calibrated against observed spoil groundwater chemistry at Diplomat and Vesta Mines in the Battle River Mining area, Highvale Mine in The Lake Wabamun mining area, and has been used to predict groundwater chemistry at Paintearth mine in the Battle River Mining area. In another similar part of the study, an increase in spoil groundwater total dissolved solids from 4400 to 5400 mg/l as a result of flyash disposal was found to be predictable using an aqueous geochemical model (Cheel and Trudell, in press). Work is continuing to refine the methods developed for predicting quantitatively the chemistry of groundwater in mine spoil.

We have found no evidence of salt being transported to the spoil surface by groundwater discharge (Trudell and Moran, 1982), nor have we found any evidence of perching of water at the interface between replaced soil and spoil (Howard and Moran, 1983). The main mechanisms of potential soil salinization appears to be upward transport of water and salt by capillary rise from the water-table where it is sufficiently close to the surface. A second potentially significant factor in soil salinization is the formation of water holding depressions by differential subsidence of spoil (Dusseault and Soderberg, 1982; Dusseault et al., 1983).

On the basis of the preceeding discussion we conclude that significant progress has been made toward resolving subobjective A-1 but considerable work remains to be done. Weathering of spoil has been shown not to be a critical process and groundwater discharge has been shown not to be a major factor in soil salinization in mine spoil. It should be noted that discharge of more saline groundwater in favourable topographic settings adjacent to reclaimed areas can be enhanced and lead to increased soil salinization outside the area that has been mined (Trudell and Moran, 1984). Although work during the final year of phase 1 began study of capillary transport of salt, further work is needed to quantify those factors governing upward transport of salt as well as the factors determining the transient and final position of the water-table.

<u>Subobjective A-2</u>

To assess and evaluate the effectiveness of topographic modification and selective placement of materials to mitigate deleterious impacts on chemical quality of groundwater.

Study of potential selective placement of overburden was predicated on the assumption that significant differences would be found between overburden materials in terms of their susceptibility to weathering release of high levels of salt. Although the salt production potential of overburden material has been found to vary by a factor of more than 10, even at the low end of the range sufficient salt is available to produce severely degraded chemical quality in the groundwater that resaturates the spoil. For this reason, our concern has focused more strongly on using topographic configuration to control post-mining hydrology and thereby control the impact of the degraded groundwater on the landscape.

Progress toward the second aspect of this subobjective has focused on the role of ponds in the post-mining landscape. Ponds appear to influence the rate at which spoil resaturates. In areas of approximately the same age, the resaturation of spoil is significantly more advanced where ponds are present than where they are absent. The height of the water table in spoil appears to be strongly controlled by the presence of ponds. Where ponds are present in spoil at Vesta mine, the water table in the spoil is several metres above the pre-mining level. It is not yet clear whether this is solely a result of the ponds or whether the elevated topography of the spoil alone would produce a steady-state water table at the same level. Considerably greater work is required to quantify the various aspects of ponds and other landscape features as they influence final water-table configuration in reclaimed landscapes.

Subobjective A-3

To assess the availability of water supply in or beneath cast overburden to support post-mining land use. Includes both quantity and quality considerations.

In most potential mine areas in the plains area of Alberta, farming is the principal land use. In most of the province, the water supply needs of these farms are met by individual wells located very close to the point of use for the water. We have evaluated the potential for developing a similar type of water supply following reclamation at both the Battle River (Trudell, et al., in press,b) and Highvale sites (Trudell, in press,a; Trudell and Faught, in press).

Mining in the Battle River area will remove the Paintearth and Battle River Coal Beds, the two most productive aquifers currently supplying local water supply demands (Trudell and Li, 1981; Trudell et al., in press,a). In the eastern part of the mine area, approximately east of Highway 855, the "Deep Sandstone", a sandstone bed located about 60 m beneath the Battle River Bed, is capable of producing adequate amounts of water with sufficiently high chemical quality to meet individual farm domestic and stock watering needs. In the western part of the mine area, water in the "Deep Sandstone" is of degraded quality and is too saline for human consumption and only marginally acceptable for stock watering. No groundwater supply that would not require treatment was found in the western part of the proposed mining area although four sandstone units beneath the Battle River Bed were evaluated. No coarse-grained sediment that could be developed to support a distribution system was found in the fill of the Battle River or Paintearth Creek. The mine spoil itself is too impermeable to produce enough water and the chemical quality of the water in the spoil is unacceptable for human or livestock consumption (Trudell and Moran, 1983; Trudell and Faught, in prep.).

Domestic water supply requirements in the Highvale Project Area are currently met by production from aquifers in or above the Ardley Coal zone. These aquifers will be disrupted by mining, and the resulting groundwater within spoil is not suitable for exploitation because of both low yield and poor water quality. The only potential post-mining groundwater source in the Highvale Area is from sandstone bodies that form an aquifer within the upper Horseshoe Canyon Formation, situated stratigraphically below the Ardley Coal Zone. These sandstone bodies are laterally very discontinous, and where present, generally of inadequate transmissivity to meet domestic water supply needs. On the basis of 14 test sites, this aquifer is suitable for exploitation only in the area of Section 21-52-5-W5. Over the rest of the site it is not likely that significant zones of adequate transmissivity will be found, although small, local sandstone bodies might be identified by additional test drilling.

Subobjective A-4

To evaluate productivity potential of post-mining landscapes and the significance of changes in productivity as a result of mining.

The original subobjective of determining the effect of surface mining on soil productivity was modified to focus on capability for agriculture rather than productivity.

The objective of reclamation of surface mines in the plains region of Alberta in almost all cases is to produce a landscape that has a capability for agricultural production that is at least equivalent to that which existed prior to mining. The Canadian Land Inventory (CLI) system (Canada Land Inventory, 1965) of rating capability for agriculture has been used to provide a basis to evaluate existing capability in the pre-mining setting from information obtained in a soil survey of the study area (Macyk and MacLean, 1983). A new classification for reclaimed landscapes has been developed on a conceptual basis identical to the CLI (Macyk, 1984a; Macyk, 1984b).

Capability for agriculture has been chosen as the basis for evaluating the product of reclamation rather than productivity primarily because capability considers intrinsic properties of the landscape. Productivity, on the other hand, addresses a parameter that is very much subject to alteration by management practices. In simple terms, a given level of productivity can be achieved from either good land with minimal management input or poorer land with greater management input. The significance of this is that in the latter case, removal of the management inputs results in immediate deterioration of productivity. Therefore, using productivity as a measure of performance of reclamation does not allow separation of the relative contributions of the land itself and the management inputs. Put in economic terms, it is clearly the intent of reclamation legislation in Alberta that the cost of assuring agricultural productivity in the post-mining landscape is to be borne as a capital investment in the land rather than as an operating cost by the farmer. Capability provides a superior measure of adherence to that intent than does productivity.

Work is continuing to evaluate the productivity of reclaimed lands relative to unmined lands within individual capability classes subjected to the same management inputs.

Subobjective A-5

To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

The settlement of the surface of reclaimed landscapes has been shown to be a significant process affecting the utilization of the landscapes for agriculture. Although current operational procedures at the mines under study accommodates the early settlement by regrading of the surface approximately one year after initial grading, our studies suggest that this practice is unlikely to solve the problem. Resaturation of the spoil has been shown to be a significant factor in producing compaction and therefore settlement (Dusseault et al., 1984b). Further rise of the water-table in the spoil after this second grading, which seems almost a certainty except in very rare cases, would thus reinitiate differential subsiding of the surface. Depressions produced by this type of settlement have the potential to alter post-reclamation drainage patterns and increase infiltration and recharge by increasing surface retention of water (Dusseault et al., 1984a). Periodic ponding in these depressions is a potential mechanism to transport salts from subsoils to the soil surface. Other techniques, such as regrading with scrapers rather than dozers are being attempted to minimize subsidence. Our studies are continuing to evaluate the effectiveness of these techniques.

OBJECTIVE B

To evaluate the long-term impact of mining and reclamation on water quantity and quality.

Subobjective B-1

To assess and evaluate the long-term deterioration of quality of groundwater in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.

Evaluation of hydrologic impacts of salinized groundwater from mine spoil have focused on potential degradation of surface water and groundwater supplies. We have shown that potential for contamination of such surface water bodies as the Battle River and Paintearth Creek is very low and no further work is believed needed in this direction (Trudell, in prep.). However, we have found significantly degraded water migrating laterally from reclaimed mine areas at Vesta Mine into two adjacent unmined aquifers (Trudell and Moran, 1984; Trudell, in press,b).

The groundwater in the reclaimed mine spoil at Vesta Mine is of Na^{+}-$SO_4^{=}$ composition with a mean TDS of 7000 mg/l, and individual values ranging from 4,000 to 14,000 mg/l. In the unmined coal adjacent to the mine the spoil-affected groundwater has a TDS of 2500 to 3200 mg/l, compared to natural values of 900 to 1700 mg/l. Sulfate concentrations increase from less than 50 mg/l in the natural groundwater to more than 1000 mg/l in the plume.

There is a corresponding shift in composition from Na^{+}-HCO_3^{-} (natural) to Na^{+}-$SO_4^{=}$, HCO_3^{-} (contaminated). The plume of contaminated water is approximately 2 km long and 1 km wide, and is driven by hydraulic head within the reclaimed spoil that is three to five metres higher than that in the unmined coal.

This head is associated with deep ponds in the reclaimed landscape that recharge the base of the spoil. The direction of spoil groundwater migration is opposite to the pre-mining flow direction, and is controlled by the major axis of horizontal permeability in the coal. There is little or no migration in the direction of the minor axis of permeability in the coal, despite the presence of a regional groundwater drain, a major meltwater channel, in that direction.

The plume of spoil groundwater in a thin (1 to 4 m) surficial sand aquifer adjacent to the mine has a salinity as high as 15,000 mg/l TDS, compared to the natural ranges of from 600 to 2,600 mg/l. Sulfate concentrations in the plume, at 2000 to 10,000 mg/l, are well above natural levels of less than 1200 mg/l. There is a corresponding compositional shift from the natural Ca^{2+}, Mg^{2+} -HCO_3^{-} or Ca^{2+}, Mg^{2+} -HCO_3^{-}, $SO_4^{=}$ to the contaminated Na^{+}, Ca^{2+}-$SO_4^{=}$ or Ca^{2+}, Na^{+}-$SO_4^{=}$. The plume of contaminated water is approximately 2 km long and 2 km wide. The direction of migration is to the southwest, toward an ephemeral stream channel that is underlain by glacio-fluvial sand. The hydraulic potential for the migration of this plume is provided by a water table within the spoil that is 2 to 3 m above that in the sand. The high water table in the spoil is related to a reclaimed land surface that is in places 10 metres above the undisturbed level, and to shallow ponds located high in the reclaimed landscape.

Further work is required to assess the geologic and hydrologic controls on such contamination of aquifers adjacent to mining operations. This process has the potential to generate saline seep type salinity in stratigraphically and topographically favourable sites adjacent to mined areas.

Subobjective B-2

To assess and evaluate infiltration, groundwater recharge, and groundwater-surface water interactions within cast overburden.

The purpose of this portion of the study is to measure and compare infiltration characteristics, soil water movement patterns, and recharge in mined and unmined settings. This was accomplished primarily through the installation of instruments to measure soil moisture and groundwater levels at selected sites in two study areas of different geologic and hydrologic setting (Howard, et al., in prep.).

Infiltration into soils in the reclaimed settings was higher than that observed in bedrock- derived soils in the unmined setting, but lower than that observed for till-derived soils in the unmined setting. Upslope depressional areas allowed larger quantities of infiltration than non-depressional areas. In reclaimed landscapes, small depressions tend to become ponded during snowmelt, and subsequent infiltration can move several metres into the soil. In the Battle River Study Area infiltration rates were higher at the Diplomat Mine than those observed at the Vesta Mine. In the Highvale Study Area, the rate of infiltration appears to be related to the sodium adsorption ratio.

Recharge occurs primarily in response to snowmelt and precipitation in the late spring and summer, especially to heavy rainfall periods such as those of June, 1983; a lesser response to snowmelt is observed. Infiltration into non-ponded areas accounts for a larger proportion of the total recharge than had previously been recognized; our data suggest that approximately half to three-quarters of the total recharge comes from upland areas, however further work is required to verify this conclusion. The remaining contribution is from leakage below permanently-ponded areas. In the Battle River area, recharge is occurring at a greater rate on reclaimed land than on unmined land; in the Highvale area, however, higher rates are observed in unmined land than in mined land. Recharge rates at Diplomat Mine are 1.85 time those at Vesta, 2.26 times those in the unmined areas, and 8.97 times those at Pit 01 at Highvale.

The major difference in infiltration and groundwater recharge processes in reclaimed landscapes relative to unmined landscapes appears to be deeper penetration of infiltrating water in reclaimed landscapes as a consequence of removal of natural stratification. A major enigma remains however. All three study sites have been resaturated and an apparently stable groundwater regime has been established far more quickly than should be the case given the rate at which recharge processes are currently operating. It is our suspicion that the combination of fracturing of the spoil mass and ponding of water in low areas and in subsidence depressions allows for extremely rapid influx of water into the spoil mass at rates perhaps 10 to 100 times as fast as in the unmined landscape. The presence of the water then causes the spoil to slake and compact sealing off the cracks and fissures and slowing the rate of influx of water to the value that we currently observe. If this is an important process in resaturation of spoil, it has significant implications for many aspects of stabilizing of reclaimed landscapes, ranging from surface subsidence, to cessation of overburden weathering, to the establishment of a stable post-mining groundwater regime in the spoil. Further work is required to assess this early resaturation process and its relationship to the ultimate hydrologic regime in reclaimed lands.

<u>Subobjective B-3</u>

To characterize the groundwater chemistry generated within cast overburden.

The chemistry of groundwater in mine spoil at the three study sites has been sufficiently characterized to provide a basis for other related studies (Trudell and Faught, in prep.). The only element of work that is continuing is the periodic sampling of a small number of wells to evaluate changes in chemistry over time.

Subobjective B-4

To assess and evaluate surface water hydrology, runoff, erosion, and sediment yield from mined land.

No work has been undertaken to evaluate erosion and sediment production of reclaimed landscapes during the first phase of study. This will become a component of evaluation of various landscape alternatives that are being studied in the next phase of study.

ACKNOWLEDGEMENTS

This research is supported by the Alberta Heritage Savings Trust Fund, administrated by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council.

REFERENCES

Canada Land Inventory. 1965. Soil Capability Classification for Agriculture. The Canada Land Inventory Report No. 2. Environment Canada, Ottawa. 16 pp.

Cheel, D. B. and M. R. Trudell. (in press). Groundwater Chemistry Associated with In-pit Disposal of Coal Ash: Predictive Geochemical Modeling Based on Laboratory Leaching Experiment: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Dusseault, M. B., J. D. Scott, H. Soderberg, and S. Moran. 1984a. Swelling clays and post-reclamation mine subsidence in Alberta. In Proceedings: 5th International Conference on Expansive Soils, Adelaide, Australia.

Dusseault, M. B., J. D. Scott, G. Zinter and S. R. Moran, 1984b. Simulation of spoil pile subsidence. In Proceedings: Fourth Australia-New Zealand Conference on Geomechanics, Perth, Western Australia. May 14-18, 1984.

Dusseault, M. B., and H. Soderberg. 1982. Geomechanical Investigation of Post Reclamation Subsidence of Prairie Strip Mine Spoil; In Ziemkiewicz, P., Proceedings of the Alberta Reclamation Conference, April, 1982, Edmonton Alberta: Canadian Land Reclamation Association, Pub. 82-1, p. 149-166.

Dusseault, M. B., S. R. Moran, J. D. Scott and H. Soderberg. 1983. Post-reclamation Subsidence of Strip Mine Cast Back Overburden: In Proceedings of the 36th Canadian Geotechnical Conference, Geotechnical Research and its Application to Canadian Resource Development, Vancouver, 1983, p.5.5.1 to 5.5.7.

Howard, A. and S. R. Moran. 1983. Soil Moisture Movement Studies on Reclaimed and Unmined Land, Battle River Area, Alberta (Preliminary results 1983): p. 273-301; In Fedkenhuer, A. W. (ed) Proceedings: Second Annual Alberta Reclamation Conference, Edmonton, Feb. 23-34, 1983: Canadian Land Reclamation Association, CLRA/AC 83-1.

Howard, A., M. R. Trudell, S. R. Moran, B. Monroe, G. J. Sterenberg. (in prep.). Infiltration and Recharge in Mined and Unmined Settings in East-central Alberta. Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Macyk, T. M., and A. H. Maclean. 1983. Soil Survey of the Plains Hydrology and Reclamation Program - Battle River Project Area. Soils Department, Alberta Research Council.

Macyk, T. M. 1984a. An Agricultural Capability Rating System for Reconstructed Soils: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Macyk, T. M. 1984b. An Agricultural Rating System for Reconstructed Soils. In Proceedings: Ninth Annual Meeting, Canadian Land Reclamation Association, Aug. 21-24, 1984. Calgary, Alberta.

Parkhurst, D. L., D. C. Thorstenson and L. N. P. Plummer. 1980. PHREEQE - A Computer Program for Geochemical Calculations. United States Geological Survey. Water Resources Investigations 80-96. NTIS Report No. USGS/WRD/WR1-80/018.

Schwartz, F. W. and A. S. Crowe. 1984. Simulation of Changes in Ground Water Levels Associated with Strip Mining. Bull. Geol. Soc. Assoc. (in press).

Schwartz, F. W., A. S. Crowe, and S. R. Moran. 1982. Model Studies on the Impact of Mining on Groundwater Flow Systems; In Proceedings of the 2nd National Hydrogeological Conference, Winnipeg, Feb. 4-5, 1982, p. 70-80.

Trudell, M. R. (in prep.). Impacts of Surface Mining on Chemical Quality of Surface Water: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Trudell, M. R. (in press,a). Post-mining Groundwater Supply Potential of the Highvale Mine Site: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Trudell, M. R. (in press,b). Potential Contamination of Shallow aquifers by Surface Mining of Coal: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Trudell, M. R., D. Cheel, and S. R. Moran. 1984a. Post-mining Groundwater Chemistry and the Effects of In-Pit Coal Ash Disposal: Predictive Geochemical Modeling Based on Laboratory Leaching Experiments. In Proceedings: Ninth Annual Meeting, Canadian Land Reclamation Association, Aug. 21-24, 1984. Calgary, Alberta.

Trudell, M. R., and R. L. Faught. (in press). Hydrogeology and groundwater chemistry of the Highvale Mining area: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Trudell, M. R., and R. L. Faught. (in prep.). Chemistry of Groundwater in Mine Spoil: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Trudell, M. R., R. L. Faught and S. R. Moran. (in press,a). Hydrogeology and Groundwater Chemistry of The Battle River Mining Area: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Trudell, M. R., and R. C. Li. 1981. Post-mining Water Supply at a Site in the Plains of Alberta. (Abstract), Geological Association of Canada, Joint Annual Meeting, May 11-13, 1981, Calgary, Alberta. pA-56. Abstracts Volume 6.

Trudell, M. R., A. Maslowski, E. Wallick, and S. R. Moran. 1983. Prediction of Groundwater Chemistry in Reclaimed Landscapes, In Fedkenheuer, A. W. (ed) Proceedings: Second Alberta Reclamation Conference, Edmonton, Alberta, February 1983. Alberta Chapter, Canadian Land Reclamation Association, Pub. #CLRA/AC 83-1, pp. 238-251.

Trudell, M. R. and S. R. Moran. 1982. Spoil Hydrogeology and Hydro-chemistry at the Battle River Site in the Plains of Alberta: In Graves, D. H. and DeVore, R. W., (eds.), Proceedings of the 1982 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December, 1982: University of Kentucky Office of Engineering Services Bulletin 129, p. 289-297.

Trudell, M. R., and S. R. Moran. 1983. Chemistry of Groundwater in Coal Mine Spoil, Central Alberta. (Abstract), The 66th Canadian Chemical Conference, Chemical Institute of Canada, Calgary, Alberta, June 5-8, 1983.

Trudell, M. R., and S. R. Moran. 1984. Off-site Migration of Spoil Groundwater, East Central Alberta. (Abstract). 13th Annual Rocky Mountain Groundwater Conference, Great Falls, Montana, April 8-11, 1984. Montana Bureau of Mines and Geology Special Publication 91.

Trudell, M. R., S. R. Moran, E. I. Wallick, and A. Maslowski Schutze. 1984b. Prediction of Post-Mining Groundwater Chemistry in Reclaimed Coal Mine Spoil, Central Alberta. (Abstract). Geological Association of Canada Annual Meeting, London, Ontario, May 14-16, 1984. Abstracts Volume 9, p. 112.

Trudell, M. R., G. J. Sterenberg and S. R. Moran. (in press,b). Post-mining Groundwater Supply at the Battle River Site, East-central Alberta: Alberta Land Conservation and Reclamation Council Report #RRTAC 84- .

Wallick, E. I. 1983. Gas composition in the unsaturated zone as an index of geochemical equilibrium in reclaimed landscapes: p. 225-237; In

Fedkenhuer, A. W. (ed). Proceedings: Second Annual Alberta Reclamation Conference, Edmonton, Feb. 23-24, 1983: Canadian Land Reclamation Association, CLRA/AC 83-1.

Wallick, E. I., M. Trudell, S. R. Moran, H. R. Krouse, A. Shakur. 1983. Chemical and Carbon Isotopic Composition of Gas in the Unsaturated Zone as an Index of Geochemical Activity in Reclaimed Mined Lands, Alberta, Canada: poster presentation at International Symposium on Isotope Hydrology in Water Resources Development, I.A.E.A. -SM-270, Vienna, Austria, 12-16 Sept., 1983.

HIGHVALE SOIL RECONSTRUCTION
RECLAMATION RESEARCH PROGRAM

M. M. BOEHM, V. E. KLAASSEN, AND L. A. PANEK
MONENCO CONSULTANTS LIMITED, CALGARY, ALBERTA

ABSTRACT

Experimental plots were established in 1982 at Highvale Mine to test several hypotheses relative to reclamation of sodic minespoil and to provide interpretive data for reclamation planning and post-mining land management.

Data collected during the first monitoring program in 1983 showed that soil moisture, bulk density, chemistry and crop productivity were significantly affected by the various treatment components for both the subsoil depth and slope drainage experiments.

As this is the first year of monitoring on these plots, the conclusions presented should be regarded as interim conclusions only.

INTRODUCTION

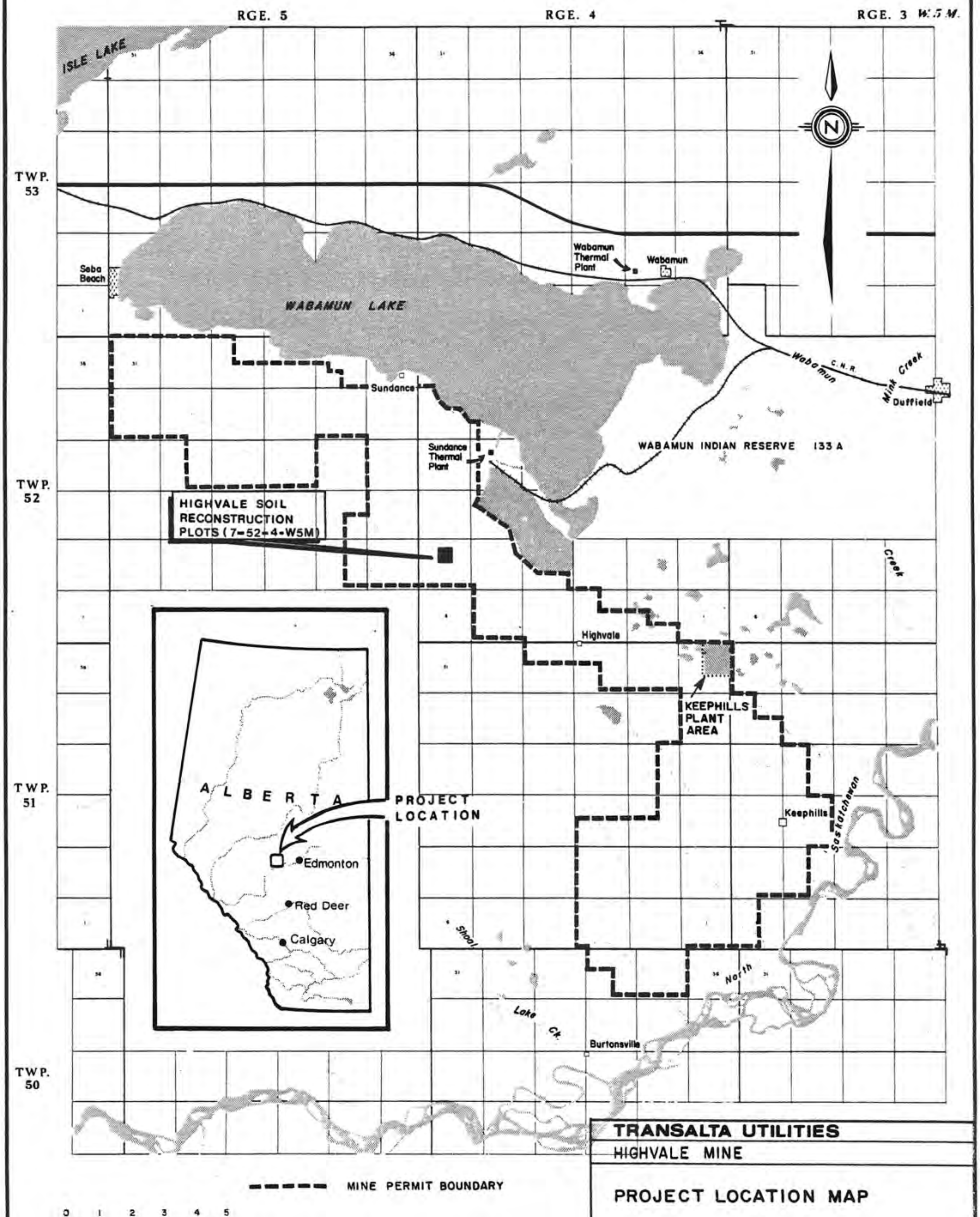
Experimental plots were established in 1982 at Highvale Mine to test several hypotheses relative to reclamation of sodic mine spoil and to provide interpretive data for reclamation planning and post-mining land management. TransAlta Utilities Corporation provided construction funding for the research plots located in Section 7, Township 52, Range 4 west of the 5th Meridian (Plate 1). Monenco Consultants Limited supervised the construction as well as selection, sampling and analyses of topsoil, subsoil and minespoil.

The subsequent monitoring programs including those discussed in this paper are funded from the Alberta Heritage Savings Trust Fund through the Land Conservation and Reclamation Council. Project management is the responsibility of Alberta Environment's Research Management Division.

The primary objectives of the program are:

1. To determine an optimum depth of subsoil replacement over minespoil to ensure adequate vegetative productivity, especially in the Highvale Mine Permit area.

2. To establish productive agricultural soil on reclaimed land. This involves assessing the sustainability of re-established



TRANSALTA UTILITIES

HIGHVALE MINE

PROJECT LOCATION MAP

MONENCO LIMITED

1982 MAR 4 DATE	CPL 8209-0 WORK ORDER 000002 SUBCODE 021 SYSTEM	PLATE 1

productivity; at the Highvale Mine emphasis is placed on minimizing salt migration from mine spoil into the root zone. Salt movement will be monitored.

3. To examine treatments which could minimize soil quantities needed to restore the original productivity of the lands. Slope configurations are evaluated as methods of minimizing the quantities of subsoil material required to maintain adequate plant productivity.

Two separate experimental plots, the Subsoil Depth Experiment, and the Slope Drainage Experiment, were constructed to provide data relative to the objectives discussed above. Each experiment was designed to test certain null hypotheses.

Subsoil Depth Experiment - Null Hypotheses

1. Crop productivity on reclaimed sodic spoil is not a function of subsoil depth (subsoil is defined as non-sodic soil material placed between spoil and replaced topsoil). If rejected, identify optimal subsoil depth.

2. Forage and grain crops will not respond differently to varying subsoil depths. If rejected, identify optimal subsoil depth for each crop.

3. The subsoil/sodic minespoil interface will not interfere with vertical movement of water. If rejected, quantify the effect.

4. Salts will not migrate from sodic minespoil into subsoil. If rejected, quantify the effect.

Slope Drainage Experiment - Null Hypotheses

1. Downslope salt transport is independent of slope and aspect. If rejected, quantify effect of slope and aspect.

2. Crop productivity is not a function of slope position, slope steepness or aspect in the reclaimed landscape. If rejected, quantify effect of slope steepness, slope position and aspect.

PROJECT DESIGN

Experimental designs and the assumptions made for each experiment in the study are described below.

Subsoil Depth Experiment - Treatments and Experimental Design

Treatments

1. Subsoil depths: 0, 0.25, 0.50, 1.00, 1.50 and 3.00 m.

2. Crops: forage/bromegrass and small grain rotation (barley, oats). This crop combination was chosen from those grown successfully in the area.

Experimental Design

The experimental design used for this experiment is a split plot with the six subsoil depths randomized in the main plots and the two crops (a forage and a cereal) randomized in the subplots. The total number of replications is three. The layout of the subsoil depth experiment, showing the randomized treatments, is illustrated in Figure 1.

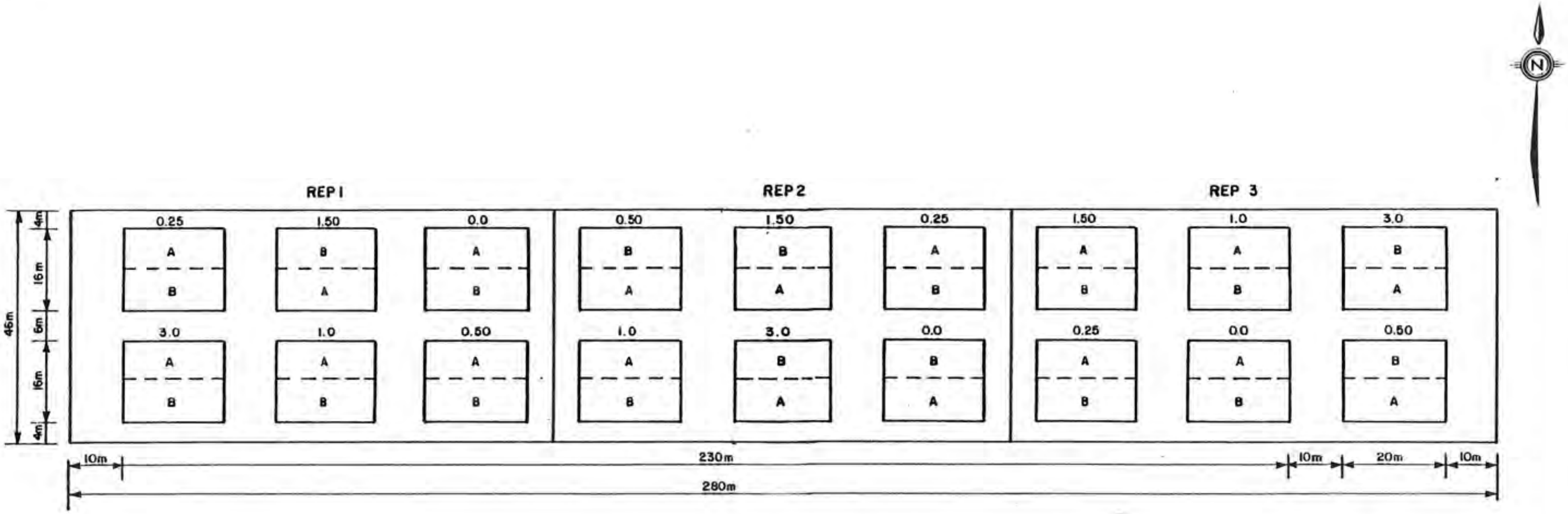
Slope Drainage Experiment - Treatments and Experimental Design

Treatments

1. Slope Type - North facing at 5° slope;
   - North facing at 10° slope;
   - South facing at 5° slope; and
   - South facing at 10° slope.

2. Position on Slope: Top half of slope;
   Bottom half of slope; and
   Pad at base of slope.

MONENCO CONSULTANTS LIMITED



A - ALFALFA (RAMBLER) AND BROMEGRASS (CHARLTON)
B - BARLEY (KLONDIKE)
0.0 NO SUBSOIL
0.25 0.25 m SUBSOIL
0.50 0.50 m SUBSOIL
1.00 1.00 m SUBSOIL
1.50 1.50 m SUBSOIL
3.00 3.00m SUBSOIL

FIGURE 1
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SUBSOIL EXPERIMENT LAYOUT

Experimental Design

Since slope steepness, slope aspect and position are treatments applied in strips rather than randomly, the precision for testing these main effects is sacrificed for increased sensitivity to interaction effects (Cochran and Cox 1957, page 307). Since interaction between slope aspect and slope steepness is internal to the experimental design, these two treatments may be combined to form a "slope type" treatment which can be randomly applied in three complete blocks. Across these whole plots or main treatments, the testing of three different slope positions introduces a "factor" again applied in strips and which can then be analyzed as a "strip-plot" or "split-block" design (Little and Hills 1978, page 115).

The layout of the slope drainage experiment is illustrated in Figure 2.

METHODOLOGY

FIELD PROGRAM

A baseline soil/spoil inventory was conducted in the fall of 1982, and neutron probe access tubes were installed.

MONENCO CONSULTANTS LIMITED

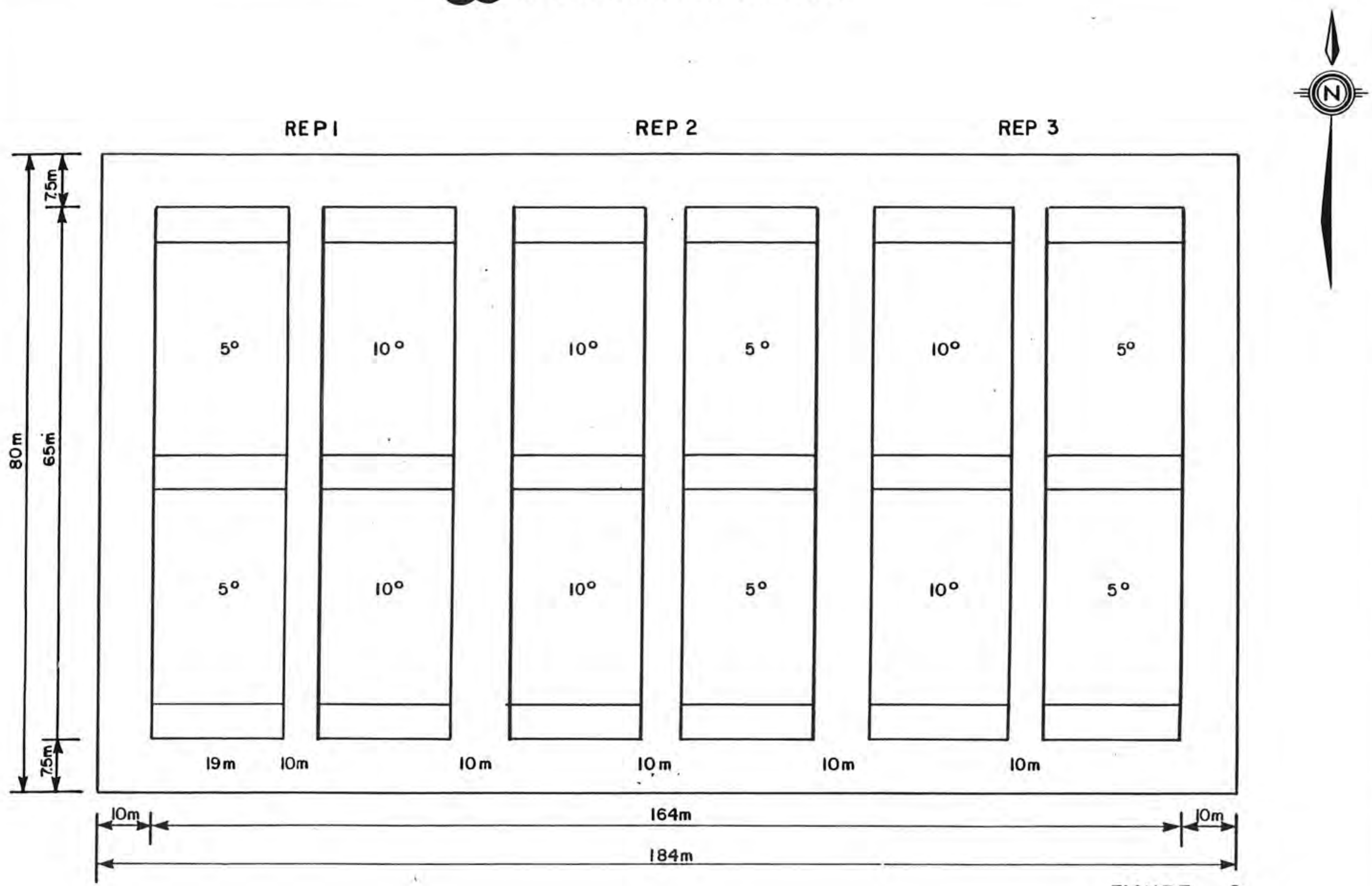


FIGURE 2
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SLOPE EXPERIMENT LAYOUT
(NOT TO SCALE)

FORAGE CROP

The 1983 field program consisted of soil moisture monitoring, soil density monitoring, gravimetric sampling, soil sampling for fertilizer requirements, weed control, site preparation, selection of seed, seeding, harvesting, crop observation, plot maintenance and soil/spoil sampling.

1. Soil Moisture and Density Monitoring

Neutron probe monitoring was conducted monthly from April through October except in June due to continuous excessive rain. A total of 108 neutron access tube locations were monitored throughout the reconstructed profiles. Neutron probe density measurements were taken concurrent with the April and October soil moisture monitoring program.

The method of neutron probe calibration as discussed by Nakayama and Reginato (1982) was used to calibrate the probe.

2. Soil/Spoil Sampling

Soil samples were collected from the sampling intervals suggested by the PCRRP Steering Committee at two sites randomly selected in each subsoil subplot. Additional samples were taken where anomalies in soil depth occurred. Two locations from each of the slope positions on the slope experiment were also sampled.

A truck mounted B24 auger rig equipped with a 60 cm long by 5 cm diameter split tube sampler with a modified cutting head was used to penetrate the plots. The experiment necessitated sampling immediate above and below topsoil/subsoil and subsoil/spoil contacts.

STATISTICAL ANALYSES

Collected data were entered onto a computer data storage file. Since the subsoil/minespoil interface was variable within treatments, a coding system was used to identify each sample as to its position relative to the measured interface for ease of statistical analyses.

Statistical analyses of the stored data were performed utilizing the PROC MEANS, PROC GLM, PROC ANOVA and PROC CORR procedures of the SAS package (SAS 1979).

Calculated statistics included means, standard deviations, coefficients of variability, analysis of variance, and linear and step-wise regressions.

RESULTS AND DISCUSSION

SUBSOIL EXPERIMENT

Soil Moisture

Table 1 shows the mean values and standard deviations of moisture in the topsoil, subsoil and minespoil of the forage and cereal subplots for each treatment during the period from April through October 1983. The reported July results are a combination of two sets of readings taken in July.

ANOVA and the Waller-Duncan K-ratio t-test performed on the data show the following results:

- mean topsoil moisture was generally significantly lower than mean subsoil and minespoil moisture (at the 95% level, Pr>F = 0.0001).

- mean monthly moisture through the profile is significantly different across the treatments for each month.

- the forage subplots were generally moister than the cereal subplots.

Soil moisture profiles for the 1.0 m treatment are shown in Figure 3. A general increase in moisture at the subsoil/minespoil interface in

TABLE 1

MONTHLY TOPSOIL, SUBSOIL AND MINESPOIL MOISTURE % BY TREATMENT FOR EACH SUBPLOT

*TREATMENT	***MATERIAL (TS, SS, MS)	ALFALFA SUBPLOT												BARLEY SUBPLOT											
		**APRIL u		MAY t		JULY s		AUG x		SEPT w		OCT v		APRIL u		MAY t		JULY s		AUG x		SEPT w		OCT v	
		x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd
0.00 m	TS	–	–	–	–	33.25	2.50	19.71	2.96	24.73	2.02	29.77	2.33	26.30	–	–	–	32.15	4.18	16.16	0.81	24.42	1.63	29.31	2.49
a																									
	MS	30.90	2.90	30.97	2.99	31.09	2.89	27.88	2.82	29.95	2.27	31.92	2.99	30.98	3.13	30.43	2.73	31.48	2.52	26.98	2.84	30.32	2.76	32.37	1.90
0.25 m	TS	–	–	–	–	30.90	2.57	21.32	2.24	24.99	1.59	29.45	1.44	–	–	–	–	29.97	3.70	19.64	1.17	24.21	0.65	29.86	1.21
cd	SS	31.72	1.11	32.45	1.59	32.75	0.85	31.75	1.67	29.35	1.88	30.39	1.79	32.35	1.20	33.14	1.67	32.59	1.64	27.65	2.12	26.93	1.81	29.45	2.31
	MS	30.69	1.76	31.95	2.00	32.07	1.67	32.40	1.63	32.11	1.51	32.93	1.55	32.83	2.80	31.31	2.42	32.70	2.19	32.17	1.87	31.16	1.82	31.45	1.56
0.50 m	TS	–	–	–	–	32.24	1.78	21.45	1.71	24.78	1.59	29.75	1.32	–	–	–	–	29.88	2.47	20.39	1.73	24.94	0.98	29.90	1.25
b	SS	32.45	1.56	32.15	1.45	33.35	1.12	32.22	2.65	29.45	2.72	30.30	2.47	31.87	1.33	32.41	1.77	32.75	1.47	31.10	2.20	28.83	2.46	30.22	1.77
	MS	30.35	1.24	34.77	4.39	33.93	4.15	33.04	2.91	33.04	3.65	31.63	1.45	30.09	1.62	30.59	1.54	30.17	1.82	30.75	2.15	30.03	1.90	30.65	1.74
1.00	TS	–	–	–	–	31.63	2.43	20.89	1.76	24.76	1.43	30.37	1.38	–	–	–	–	30.60	2.63	19.99	1.71	24.64	0.72	29.55	2.59
d	SS	31.36	1.34	31.43	2.33	33.04	1.55	30.29	2.50	29.58	2.03	30.94	2.35	30.56	1.39	32.04	1.84	32.08	1.55	30.03	2.79	28.86	2.55	30.00	2.49
	MS	31.34	1.37	32.24	1.81	32.33	2.16	31.39	1.65	31.62	1.69	31.62	1.70	29.14	2.20	31.18	2.92	29.64	2.49	29.58	2.20	29.11	1.91	29.35	1.62
1.50	TS	–	–	–	–	31.84	2.14	22.62	0.64	26.77	1.69	29.36	1.29	–	–	–	–	31.51	3.25	21.61	0.91	25.65	1.37	28.01	1.41
bc	SS	31.03	2.07	31.61	2.40	32.84	2.64	32.17	2.27	31.33	2.67	30.98	2.38	30.58	2.11	31.28	2.00	31.95	2.37	30.64	2.78	29.90	2.87	30.02	2.44
	MS	32.42	2.05	30.98	2.29	31.70	3.26	32.27	2.89	31.57	2.71	31.59	2.84	30.44	2.41	30.90	2.13	29.78	3.67	30.11	2.68	29.95	2.95	29.37	3.37
3.00	TS	–	–	–	–	33.99	3.27	23.15	1.17	26.20	0.72	24.68	0.47	–	–	–	–	32.02	1.97	20.09	0.71	26.58	1.08	24.77	1.07
a	SS	31.69	0.49	31.78	1.09	33.40	1.75	31.20	1.17	31.63	1.46	30.47	1.99	32.02	1.46	32.20	1.38	32.61	1.44	30.94	1.93	31.56	1.79	30.50	2.33
	MS	29.89	1.15	31.62	1.98	29.72	2.39	31.17	1.68	29.44	2.46	27.75	1.31	28.82	0.52	30.63	2.92	30.80	2.30	30.50	1.98	31.29	2.09	29.95	2.68

Letters indicate results of Waller-Duncan K-ratio t-test

* Pr > F = 0.0001 at the 95% level. Treatments having the same letters are not significantly different.

** Pr > F = 0.0001 at the 95% level. Mean monthly moisture values are always significantly different.

*** Pr > F = 0.0001 at the 95% level. Topsoil, subsoil and minespoil are always significantly different.

N.B. The coefficient of variability (CV) was generally $\leq 10\%$ for all statistical tests performed.

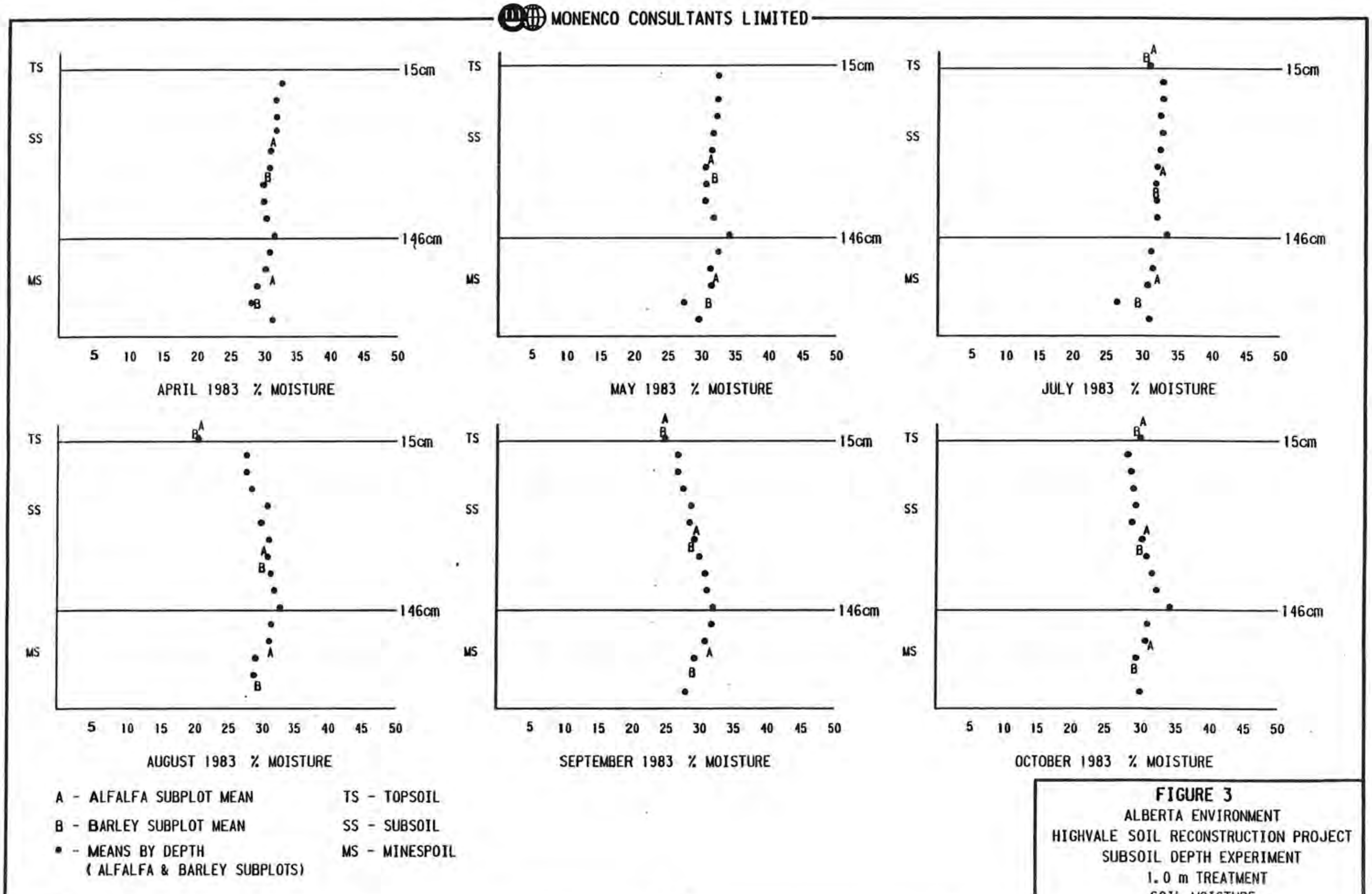


FIGURE 3
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SUBSOIL DEPTH EXPERIMENT
1.0 m TREATMENT
SOIL MOISTURE

all plots may indicate that the interface is affecting the downward vertical movement of moisture. If the trend continues and develops further, a more conclusive statement can be made about the effect of the interface on moisture movement.

Soil Bulk Density

Table 2 shows mean values and standard deviations of bulk density in the topsoil, subsoil and minespoil for the forage and cereal subplots of each treatment.

Analysis of variance and the Waller-Duncan K-ratio t-test performed on the data indicate the following results:

- bulk density increased significantly with depth. Topsoil, subsoil and minespoil bulk densities were significantly different at the 95% level ($Pr > F = 0.0001$).

- Individual bulk density values ranged from a low of 0.90 g/cc to a high of 2.12 g/cc. Mean values for topsoil ranged from 1.20 - 1.5g/cc, for subsoil from 1.59 - 1.83 g/cc and for minespoil from 1.69 to 1.87 g/cc.

A bulk density profile for the 1.0 m treatment is illustrated in Figure 4. The bulk density profile is the result of constructon and one year's settling and can be expected to change with time. Changes

TABLE 2

SOIL BULK DENSITY BY TREATMENT FOR EACH SUBPLOT

TREATMENT*	MATERIAL**	BULK DENSITY g/cc ALFALFA SUBPLOT		BARLEY SUBPLOT	
	(TS, SS, MS)	$\bar{x}$	sd	$\bar{x}$	sd
0.00 m	TS	1.40	0.16	1.36	0.22
a	SS	-	-	-	-
	MS	1.76	0.13	1.71	0.10
0.25 m	TS	1.53	0.21	1.46	0.18
ab	SS	1.76	0.11	1.78	0.17
	MS	1.86	0.13	1.87	0.20
0.50 m	TS	1.30	0.13	1.33	0.12
c	SS	1.73	0.19	1.83	0.08
	MS	1.74	0.20	1.69	0.30
1.00 m	TS	1.41	0.18	1.34	0.25
c	SS	1.68	0.17	1.64	0.13
	MS	1.87	0.09	1.74	0.14
1.50 m	TS	1.49	0.14	1.20	0.15
c	SS	1.78	0.13	1.59	0.23
	MS	1.83	0.12	1.80	0.12
3.00 m	TS	1.31	0.13	1.29	0.26
b	SS	1.65	0.13	1.78	0.16
	MS	1.85	0.18	1.79	0.12

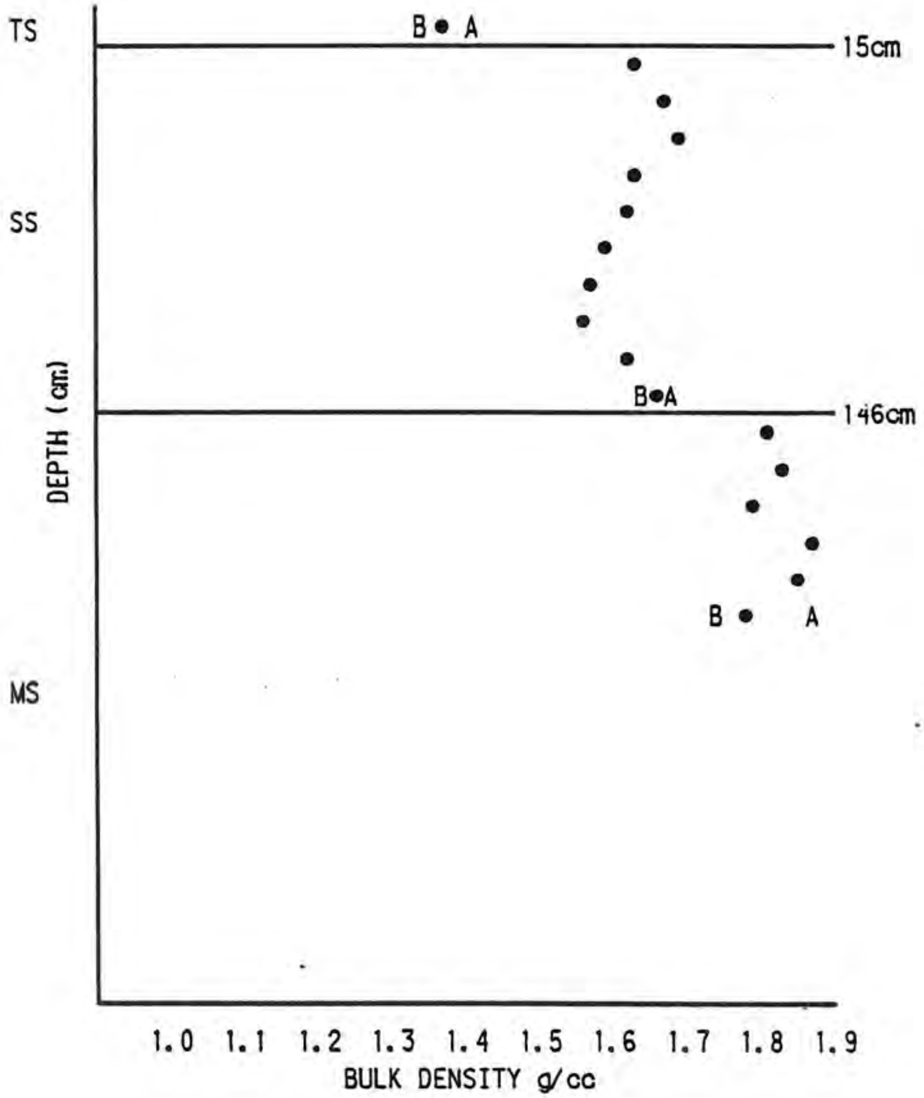
Letters indicate results of Waller-Duncan K-ratio t-test.

* Pr > F = 0.0001 at the 95% level. Treatments having the same letter are not significantly different.

** Pr > F = 0.0001 at the 95% level. Topsoil, subsoil and minespoil are always significantly different.

N.B. The coefficient of variability was generally $\leq$ 10% for all statistical tests performed.

MONENCO CONSULTANTS LIMITED



TS - TOPSOIL
SS - SUBSOIL
MS - MINESPOIL
A - ALFALFA SUBPLOT MEAN
B - BARLEY SUBPLOT MEAN
• - TREATMENT MEANS BY DEPTH

FIGURE 4
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SUBSOIL DEPTH EXPERIMENT
1.0 m TREATMENT
SOIL BULK DENSITY

N00488.CHT

will be due largely to compaction and subsidence. Some changes due to crop rooting may be expected, especially in the forage subplots. The general trends seem to indicate that compaction may already be occurring beneath the topsoil as the plots settle.

Soil Chemistry

Samples were analysed for pH, EC, soluble cations, soluble sulphate and soluble chloride. Only pH, EC, soluble sodium and SAR measurements were statistically analysed. The other parameters will be statistically analysed after a longer time interval (i.e., 5 years).

Results of soil chemical analysis for pH, EC, soluble sodium and SAR are presented in Table 3, and chemistry profiles for the 1.0 m treatment are shown in Figure 5.

There were no significant differences between replicates or subplots for pH, EC, soluble sodium or SAR at any of the depth intervals. This indicates that each of the topsoil, subsoil and spoil materials used in plot construction were relatively homogeneous across the experimental area and with depth. Significant differences between treatments by depth interval reflect increases of soluble sodium, EC and SAR at the subsoil/spoil depth interval for each treatment. This is further confirmed by results of the Waller-Duncan K-ratio t-test. Both topsoil and subsoil material are significantly different from the spoil material.

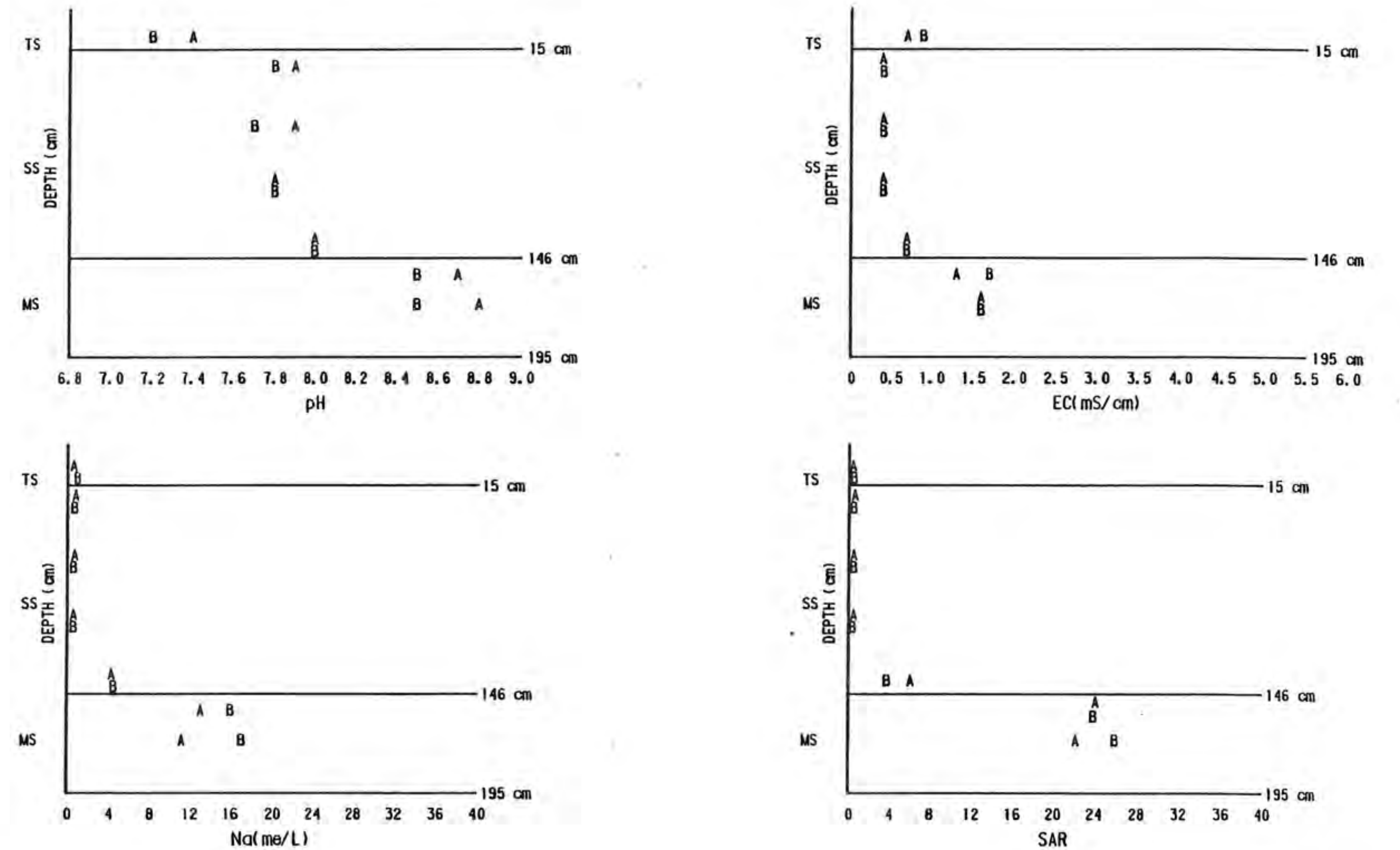
TABLE 3

Chemical Analysis of Depth Intervals - Subsoil Depth Experiment

Treatment	Depth	Material	CEREAL pH		CEREAL EC (mS/cm)		CEREAL Na(me/l)		CEREAL SAR		FORAGE pH		FORAGE EC (mS/cm)		FORAGE Na (me/l)		FORAGE SAR	
(m)			$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	S
0.00	0-15	Topsoil	7.2d*	0.2	3.4a	0.2	3.4d	2.1	2.3d	1.6	7.3c	0.4	0.8c	0.2	3.6c	2.5	2.7d	2.0
	15-40	Spoil	8.5a	0.1	1.6c	0.2	14.7c	2.1	21.0c	2.5	8.5a	0.1	1.76	0.5	16.1b	4.5	23.1a	3.2
	40-55	Spoil	8.5a	0.3	1.6c	0.3	15.1b	3.3	22.2b	2.5	8.3b	0.4	2.5a	2.6	24.7a	26.5	22.1b	9.6
	105-120	Spoil	8.4c	0.2	1.9b	0.5	18.3a	4.5	24.4a	3.3	8.3b	0.3	2.5a	1.7	23.9a	16.9	21.2c	10.4
0.25	0-15	Topsoil	7.2c	0.1	0.5b	0.1	0.4b	0.1	0.2d	0.1	7.3d	0.5	0.8b	0.4	1.9c	3.5	0.7c	0.8
	15-40	Subsoil	7.8b	0.1	0.3c	0.0	0.7c	0.3	0.5c	0.3	7.7c	0.2	0.4d	0.0	0.6d	0.3	0.5d	0.2
	55-70	Subsoil	7.8b	0.1	0.5b	0.2	2.4b	1.3	1.90b	1.0	7.9b	0.1	0.5c	0.2	3.1b	2.0	2.8b	1.9
	105-120	Spoil	8.5a	0.1	1.4a	0.2	13.5a	1.2	23.3a	1.9	8.5a	0.1	1.6a	0.4	15.4a	4.2	24.6a	2.6
0.50	0-15	Topsoil	7.2d	0.1	0.5e	0.1	0.3f	0.1	0.2e	0.1	7.5e	0.2	0.5e	0.1	0.3f	0.1	0.2e	0.1
	15-30	Subsoil	7.9c	0.2	0.3f	0.0	0.5e	0.2	0.4d	0.1	7.8c	0.1	0.4f	0.1	0.5e	0.1	0.3d	0.1
	55-70	Subsoil	8.5b	0.1	1.4b	0.2	13.3c	2.0	25.7b	2.2	8.2b	0.4	1.1c	0.6	10.1c	7.4	16.0b	12.2
	100-130	Subsoil	7.9c	0.2	0.8d	0.1	4.9d	1.4	4.0c	1.3	7.7d	8.1	0.6d	0.9	3.0d	6.5	2.5c	5.7
	130-145	Spoil	8.5b	0.0	2.1a	1.2	20.2a	11.1	25.3a	2.5	8.5a	0.2	1.5b	0.4	14.7b	4.3	24.9a	2.0
	145-165	Spoil	8.7a	0.1	1.2c	0.1	11.7b	1.2	25.2a	2.0	8.5a	0.2	1.8a	0.7	17.6a	7.2	26.5a	2.1
1.00	0-15	Topsoil	7.2e	0.3	0.9b	0.4	1.0d	1.1	0.5d	0.5	7.4f	0.7	0.7c	0.2	0.6f	0.3	0.4e	0.2
	15-30	Subsoil	7.8c	0.2	0.4d	0.0	0.7e	0.2	0.5d	0.1	7.9d	0.1	0.4d	0.0	0.8d	0.2	0.6c	0.2
	50-65	Subsoil	7.7d	0.4	0.4d	0.0	0.6f	0.1	0.5d	0.1	7.9d	0.1	0.4d	0.0	0.7c	0.3	0.5d	0.2
	85-100	Subsoil	7.8c	0.1	0.4d	0.0	0.6f	0.2	0.4e	0.1	7.8e	0.2	0.4d	0.1	0.6f	0.1	0.5s	0.1
	130-150	Subsoil	8.0b	0.2	0.7c	0.2	4.5c	1.5	3.8c	1.4	8.0c	0.4	0.7c	0.4	4.3c	4.9	3.2b	9.9
	150-180	Spoil	8.5a	0.2	1.7a	0.5	16.1b	4.7	24.0b	3.0	8.7b	0.2	1.3a	0.7	13.1b	6.5	24.2a	3.2
	180-215	Spoil	8.5a	0.2	1.6a	1.3	17.1a	9.7	26.0a	3.5	8.8a	0.2	1.1b	0.7	11.2a	6.9	22.3a	7.1
1.50	0-15	Topsoil	7.4e	0.5	0.5d	0.2	0.3f	0.1	0.2f	0.0	7.6f	0.3	0.66	0.1	0.4e	0.1	0.2f	0.1
	15-30	Subsoil	7.9c	0.1	0.4e	0.0	0.5d	0.2	0.4d	0.2	7.9c	0.1	0.4d	0.0	0.5d	0.2	0.4d	0.1
	50-65	Subsoil	7.9c	0.2	0.3f	0.1	0.4e	0.2	0.3e	0.1	7.7e	0.4	0.3e	0.1	0.5d	0.2	0.4d	0.1
	85-100	Subsoil	7.8d	0.2	0.3f	0.0	0.4e	0.1	0.3e	0.0	7.7e	0.3	0.3e	0.1	0.4e	0.1	0.3e	0.0
	120-135	Subsoil	7.8d	0.3	0.3f	0.1	0.5d	0.2	0.4d	0.1	7.8d	0.3	0.3e	0.1	0.4e	0.1	0.3e	0.1
	150-165	Subsoil	7.9c	0.3	0.3f	0.1	0.4e	0.0	0.4d	0.0	7.6f	0.3	0.3e	0.1	0.4e	0.0	0.3e	0.1
	180-200	Subsoil	7.9c	0.2	0.7c	0.3	3.9c	2.8	3.2c	2.0	7.8d	0.5	0.5c	0.3	2.2c	2.1	1.7c	1.6
	200-230	Spoil	8.3b	0.6	2.2b	1.5	20.3b	14.9	22.4b	10.9	8.7b	0.1	1.6b	0.4	14.9b	3.9	29.2b	1.6
	245-260	Spoil	8.5a	0.2	3.3a	1.2	31.9a	11.5	29.1a	3.1	8.6a	0.1	2.1a	1.0	19.0a	8.9	25.3a	1.6
3.00	0-15	Topsoil	7.6g	0.5	1.2c	1.5	6.1c	13.9	5.0b	11.5	7.5g	0.5	0.5b	0.9	0.3f	0.9	0.2e	0.8
	15-30	Subsoil	7.9e	0.1	0.4d	0.1	0.4e	0.1	0.3e	0.1	7.9d	0.1	0.4c	0.0	0.4e	0.1	0.3d	0.1
	50-65	Subsoil	7.9e	0.2	0.4d	0.1	0.4e	0.1	0.3e	0.0	7.8e	0.1	0.4c	0.0	0.4e	0.1	0.3d	0.1
	85-100	Subsoil	7.9e	0.1	0.4d	0.0	0.4e	0.0	0.3e	0.0	7.7f	0.2	0.3d	0.1	0.4e	0.0	0.3d	0.0
	120-135	Subsoil	7.8f	0.1	0.4d	0.1	0.4e	0.1	0.3e	0.1	7.8e	0.0	0.4c	0.1	0.5d	0.2	0.4c	0.1
	155-170	Subsoil	8.0d	0.1	0.4d	0.0	0.5d	0.2	0.4d	0.1	7.8e	0.1	0.4c	0.0	0.4e	0.0	0.3d	0.0
	190-205	Subsoil	7.9e	0.1	0.4d	0.0	0.5d	0.2	0.4d	0.2	7.8e	0.1	0.4c	0.1	0.5d	0.1	0.4c	0.1
	225-240	Subsoil	8.0d	0.1	0.4d	0.0	0.6d	0.2	0.5c	0.2	7.9d	0.1	0.4c	0.0	0.6c	0.2	0.4c	0.2
	285-300	Subsoil	7.9e	0.0	0.4d	0.0	0.4e	0.0	0.3e	0.0	7.9d	0.1	0.4c	0.0	0.4e	0.1	0.3d	0.1
	330-350	Subsoil	8.1c	0.2	1.1c	1.1	7.5c	9.7	6.0b	8.1	8.0c	0.1	0.7b	0.3	3.8b	1.5	2.9b	1.0
	350-365	Spoil	8.5b	0.3	2.0a	1.2	17.8b	10.8	21.9a	10.0	8.5a	0.2	2.3a	2.0	20.5a	17.1	21.0a	3.6
	395-410	Spoil	8.6a	0.3	1.6b	1.1	14.8a	10.1	22.0a	9.1	8.4b	0.3	2.3a	2.5	21.6a	23.9	21.3a	4.1

* Results of Waller-Duncan K-ratio t- test. Numbers for treatment and each soil property by depth increment followed by different letters are significantly different at the 95% level.

MONENCO CONSULTANTS LIMITED



A - FORAGE SUBPLOT

B - CEREAL SUBPLOT

TS - TOPSOIL

SS - SUBSOIL

MS - MINESPOIL

NOTE: SUBPLOT VALUES THAT ARE EQUAL ARE STACKED WITHIN AN INCREMENT.

FIGURE 5

ALBERTA ENVIRONMENT

HIGHVALE SOIL RECONSTRUCTION PROJECT

SUBSOIL DEPTH EXPERIMENT

1.0 m TREATMENT

SOIL CHEMISTRY

ANOVA results indicate that upward movement of salts from the minespoil into the subsoil has occurred since construction, and is occurring more quickly in the shallow treatments. This may be explained by the effect of crop growth on the shallower treatments. The utilization of soil moisture by plants occurs within the upper soil zone and creates a decreasing moisture gradient toward the surface. Soil moisture content decreased throughout the subsoil and topsoil materials as depth decreased. The potential moisture gradient resulted in a net upward movement of water carrying soluble salts from the spoil into the subsoil in the shallow subsoil treatments.

Crop Productivity

Both forage and cereal crop productivity were significantly different by treatment. Figure 6 illustrates crop productivity by treatment. On the forage subplots, highest yield was measured on the 0.50 m treatment. Highest yield for the cereal subplots was associated with the 1.0 m treatment. The 0.0 m treatment had the lowest yields for both crops.

SLOPE DRAINAGE EXPERIMENT

Soil Moisture

Analysis of variance and the Waller-Duncan K-ratio t-test show that the 10°N and 5°N treatments were not significantly different from each

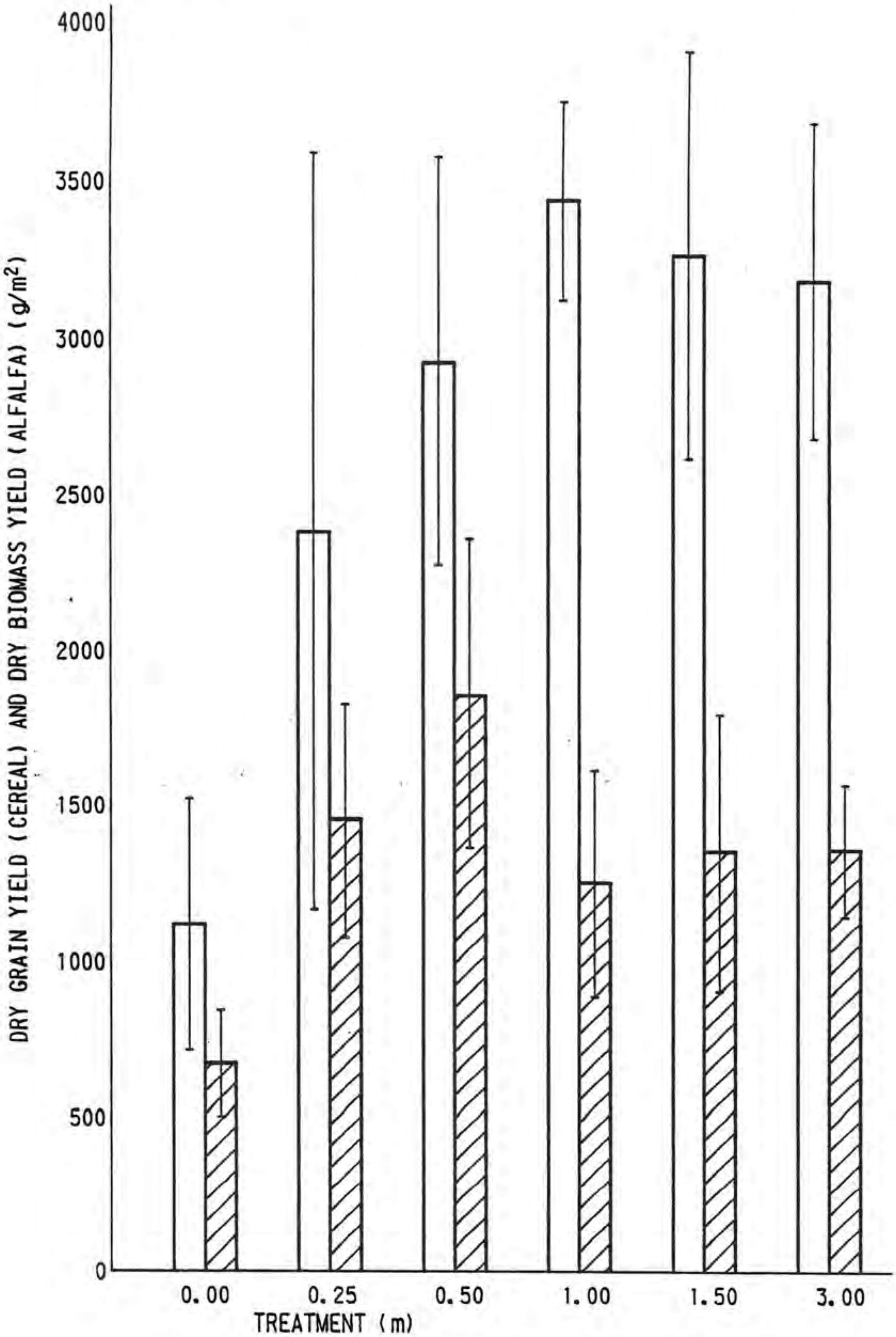


FIGURE 6
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SUBSOIL DEPTH EXPERIMENT
1983 YIELDS
BY TREATMENT (m)

N00489.CHT

other, but were significantly moister than the 10°S and 5°S treatments. Soil moisture increased significantly with depth in the topsoil, subsoil and minespoil. Material*subplot*treatment interactions are also significant at the 95% level ($Pr > F = 0.0004$).

A linear trend analysis was performed on the slope drainage experiment data to determine whether a slope effect (deviation from the linear trend) could be detected. The linear deviation was calculated by summing soil property values of upper and lower slope positions and subtracting twice the middle slope position value. The theoretical value of the calculation would be zero if there was no slope effect. Linear deviation values significantly greater or less than zero therefore represent a slope effect or change in soil property values relative to slope position. The analysis was performed on July, August, and October moisture data. The results indicate a strong trend of increasing moisture down the slope in all of the treatments during these months. The Waller-Duncan K-ratio t-test also showed that upper, middle, and lower slope positions were significantly different ($Pr > F = 0.0001$ at the 95% level).

In general, all the treatments exhibited the same soil moisture profile trends. Moisture was constant down the profile early in the season then drier in the topsoil and subsoil as the summer progressed. The upper slope positions tended to be drier than the lower slope positions. The south-facing plots were also drier overall than the north-facing plots. There were no apparent trends at the subsoil/minespoil interface.

Soil Bulk Density

Table 4 shows means and standard deviations of bulk density in the topsoil, subsoil and minespoil at lower (Subplot A), middle (Subplot B) and upper (Subplot C) slope positions for each treatment.

Analysis of variance, linear trend analysis, and the Waller-Duncan K-ratio t-test performed on the data also show that mean bulk density on the upper slope is significantly lower than that at middle and lower slope positions ($Pr > F = 0.0048$ at the 95% level). Mean bulk densities at middle and lower slope positions were not significantly different from each other.

Bulk density increased significantly with depth ($Pr > F = 0.0001$ at the 95% level).

Soil Chemistry

Results of chemical analysis for all treatments and positions are presented in Table 5 which shows means and standard deviations of soil chemical data by aspect, slope, position and depth increment. Chemical profiles for the 5°N treatment are shown in Figure 7. Results of a paired comparison t-test are also given for each depth increment within the treatment effects. The pH, EC, soluble sodium and SAR were generally significantly different between depths, and tended to increase with the depth and were significantly higher immediately above

TABLE 4

SOIL BULK DENSITY (g/cc) BY TREATMENT FOR EACH SLOPE POSITION

TREATMENT**	MATERIAL***	LOWER* a		MIDDLE a		UPPER b	
		$\overline{x}$	sd	$\overline{x}$	sd	$\overline{x}$	sd
10°Nx	TS	1.44	0.17	1.47	0.19	1.52	0.26
	SS	1.82	0.08	1.70	0.08	1.72	0.17
	MS	1.92	0.05	1.82	0.12	1.75	0.08
10°Sy	TS	1.55	0.24	1.47	0.26	1.34	0.22
	SS	1.66	0.18	1.71	0.11	1.56	0.20
	MS	1.81	0.11	1.79	0.08	1.63	0.13
5°Nx	TS	1.32	0.23	1.49	0.29	1.42	0.26
	SS	1.79	0.10	1.69	-	1.70	0.03
	MS	1.86	0.12	1.91	0.04	1.84	0.06
5°Sy	TS	1.31	0.17	1.37	0.26	1.35	0.31
	SS	1.59	0.12	1.56	0.07	1.78	0.08
	MS	1.81	0.06	1.78	0.18	1.83	0.07

Letters indicate results of Waller-Duncan K-ratio t-test

* Pr > F = 0.0048 at the 95% level. Slope positions having the same letter are not significantly different.

** Pr > F = 0.0031 at the 95% level. Treatments having the same letter are not significantly different.

*** Pr > F = 0.0001 at the 95% level. Topsoil, subsoil and minespoil are always significantly different.

N.B. The coefficient of variability was generally $\leq$ 10% for all statistical tests performed.

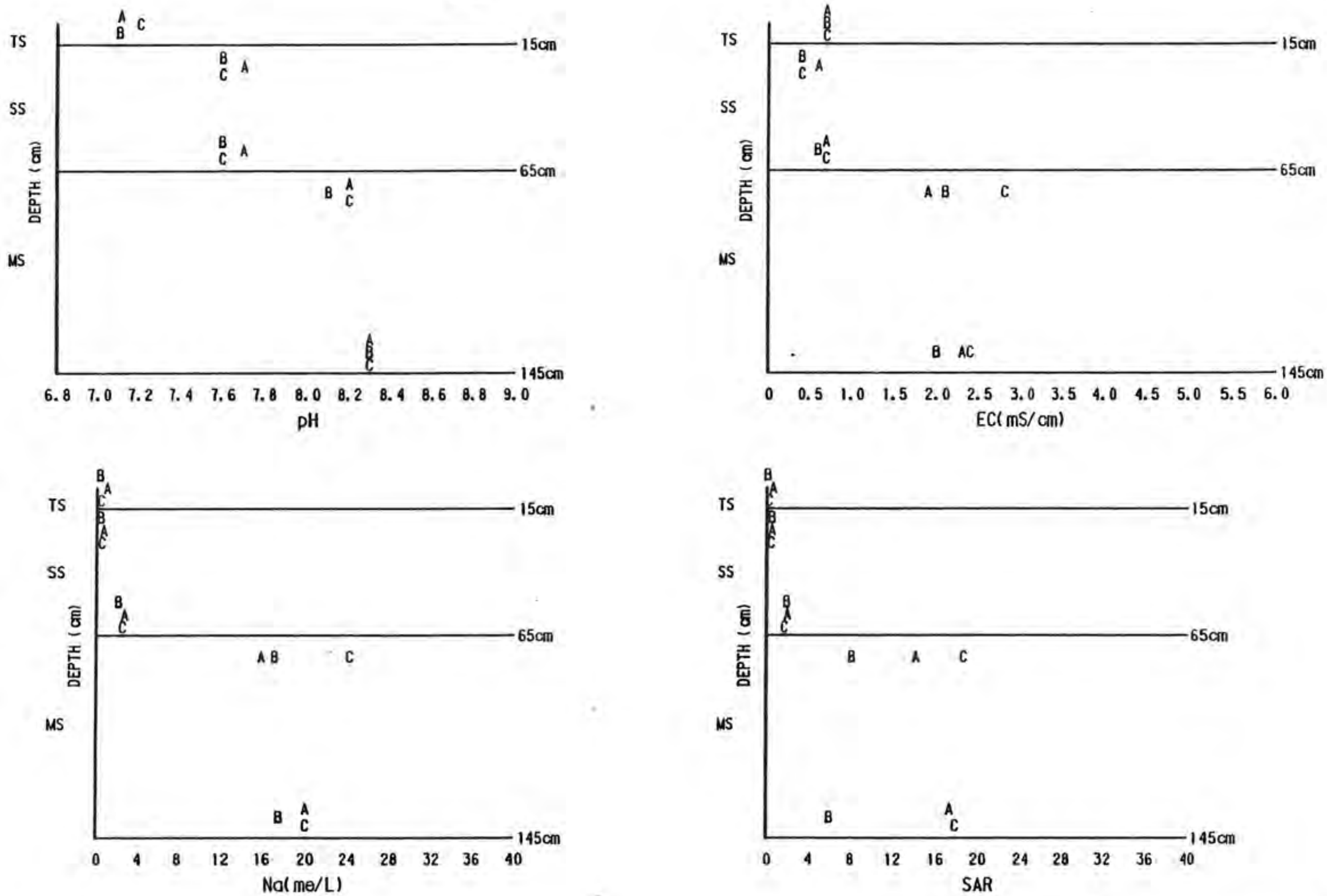
TABLE 5

CHEMICAL ANALYSIS OF DEPTH INTERVALS – SLOPE DRAINAGE EXPERIMENT – 1983

TREATMENT	DEPTH	MATERIAL	LOWER SLOPE pH		EC (mS/cm)		Na (me/l)		SAR		MIDDLE SLOPE pH		EC (mS/cm)		Na (me/l)		SAR		UPPER SLOPE pH		EC (mS/cm)		Na (me/l)		SAR	
			x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd
10°N	0-15	Topsoil	7.3d*	0.2	0.5d	0.2	0.4e	0.1	0.3e	0.0	7.4d	0.3	0.5c	0.1	0.5c	0.2	0.3c	0.1	7.2c	0.3	0.7e	0.2	0.4e	0.1	0.2e	0.1
	15-40	Subsoil	7.7c	0.2	0.4e	0.0	0.5d	0.1	0.4d	0.1	7.7c	0.1	0.5c	0.1	0.4c	0.1	0.3c	0.1	7.7d	0.2	0.4d	0.1	0.6d	0.4	0.5d	0.3
	50-65	Subsoil	7.8b	0.1	0.6c	0.1	2.4c	1.0	1.9c	0.8	7.7c	0.2	0.9b	0.3	3.1b	1.9	1.8b	1.0	7.9c	0.3	1.1c	1.2	6.8c	1.06	4.7c	7.1
	65-80	Spoil	8.3a	0.1	1.9b	0.2	16.1b	1.7	14.5b	1.1	8.2b	0.0	3.2a	1.5	25.2a	10.6	15.2a	3.4	8.2b	0.2	2.4b	0.5	20.2b	4.6	15.6b	2.8
	130-145	Spoil	8.3a	0.1	2.5a	1.6	21.1a	11.4	18.6a	7.0	8.3a	0.2	3.1a	1.5	24.1a	9.3	17.9a	7.9	8.3a	0.2	3.5a	1.7	27.4a	9.1	16.4a	1.5
10°S	0-15	Topsoil	7.4e	0.3	0.7e	0.2	0.4c	0.1	02.2e	0.0	7.4d	0.3	0.7c	0.2	0.4d	0.2	0.2d	0.1	7.3d	0.4	0.6c	0.2	0.4d	0.2	0.2d	0.1
	15-40	Subsoil	7.8d	0.1	0.4d	0.0	0.4c	0.1	0.3d	0.1	7.9c	0.1	0.4d	0.1	0.8c	0.8	0.6c	0.6	7.7c	0.2	0.4d	0.0	0.6c	0.3	0.5c	0.2
	50-65	Subsoil	7.9c	0.1	0.6c	0.1	2.5b	0.5	1.9c	0.4	7.8b	0.1	0.5b	0.1	1.2b	0.8	0.9b	0.6	7.9b	0.5	0.9b	1.0	6.1b	8.8	5.3b	8.0
	65-80	Spoil	8.4a	0.1	2.7b	0.2	23.1a	1.4	19.7b	0.9	8.3a	0.2	2.8a	0.2	22.8a	0.9	18.6a	1.4	8.3a	0.1	3.0a	1.0	24.8a	7.5	18.7a	4.0
	130-145	Spoil	8.3b	0.1	3.2a	0.6	27.9a	4.6	22.8a	2.1	8.3a	0.2	2.8a	0.4	23.2a	2.6	17.9a	4.5	8.3a	0.3	3.1a	0.9	26.0a	7.5	18.1a	3.9
5°N	0-15	Topsoil	7.1d	0.2	0.7c	0.0	1.0e	0.8	0.6d	0.5	7.1d	0.2	0.7b	0.1	0.3d	0.1	0.2e	0.0	7.2d	0.4	0.7c	0.1	0.4d	0.2	0.2d	0.1
	15-40	Subsoil	7.7c	0.2	0.6b	0.4	0.7d	0.3	0.5d	0.2	7.6c	0.2	0.4c	0.7	0.4c	0.1	0.3d	0.1	76 c	0.2	0.4d	0.1	0.5d	0.3	0.4c	0.2
	50-65	Subsoil	7.7c	0.1	0.7c	0.1	2.8c	0.7	2.0c	0.5	7.6c	0.2	0.6b	0.2	2.2b	1.8	1.5c	1.2	7.6c	0.1	0.7c	0.3	2.6c	1.8	1.7b	1.0
	65-80	Spoil	8.2b	0.1	1.9b	0.1	16.0b	2.4	14.2b	1.3	8.1b	0.3	2.1a	0.8	17.3a	8.2	13.4a	6.5	8.2b	0.2	2.8b	0.6	24.3b	5.6	18.7a	3.7
	130-145	Spoil	8.3a	0.1	2.3a	0.4	20.1a	5.6	17.4a	3.6	8.3a	0.1	2.0a	0.8	17.7a	6.1	18.3a	6.1	8.3a	0.1	2.4a	0.8	20.1a	6.3	17.9a	5.5
5°S	0-15	Topsoil	7.3d	0.3	0.6c	0.1	0.3e	0.1	0.2e	0.1	7.4e	0.6	0.9d	0.9	4.4c	10.0	3.9 c	9.1	7.4d	0.3	0.6d	0.1	0.4d	0.2	0.3d	0.1
	15-40	Subsoil	7.8c	0.1	0.4a	0.0	0.5d	0.1	0.4d	0.1	7.6d	0.1	0.4e	0.1	0.4e	0.1	0.3 e	0.1	7.9c	0.1	0.4e	0.1	0.4d	0.0	0.3d	0.0
	50-65	Subsoil	7.7b	0.2	0.6c	0.2	2.6c	1.5	2.0c	1.1	7.8c	0.2	0.7c	0.2	2.7d	1.0	2.0 d	0.6	7.9c	0.2	0.8c	0.3	3.6c	2.3	2.6c	1.6
	65-80	Spoil	8.3a	0.1	2.8b	0.5	23.1b	3.5	19.7b	4.0	8.4b	0.2	3.1b	0.3	25.7b	2.6	19.4 b	4.1	8.2b	0.2	2.6b	1.0	20.9b	8.7	17.1b	7.1
	130-145	Spoil	8.1a	0.5	2.1a	0.8	17.4a	8.6	15.8a	8.1	8.0a	0.3	2.6a	0.8	20.8a	7.2	15.4 a	4.5	7.0a	3.4	3.0a	0.5	26.1a	4.6	22.4a	4.6

*Results of Waller-Duncan K-ratio t-test across depth interval. Numbers for depth intervals followed by different letters are significantly different at the 95% level.

MONENCO CONSULTANTS LIMITED



A* - LOWER SLOPE
B - MIDDLE SLOPE
C - UPPER SLOPE

TS - TOPSOIL
SS - SUBSOIL
MS - MINESPOIL

NOTE: SUBPLOT VALUES THAT ARE EQUAL ARE STACKED WITHIN AN INCREMENT.

FIGURE 7
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SLOPE DRAINAGE EXPERIMENT
5°N TREATMENT
SOIL CHEMISTRY

N0047D.CHT

the spoil interface (50 to 65 cm) than at 15 to 40 cm. ANOVA results showed that subsoil/spoil interface values were generally significantly higher in 1983. This indicates that upward movement of sodium has occurred since 1982 across all treatments and slope positions.

The magnitude of increase in soluble sodium, EC and SAR at the subsoil/spoil interface was greatest in the upper slope position and for the 10° slope treatments. The upper slope positions were significantly higher in EC, soluble sodium and SAR than lower slope positions.

There were no significant differences in soil properties between treatments or aspects and slope analyzed separately.

Figure 8 is a schematic representation of the results of the linear trend analysis showing sodium and water movement. Deviations from the linear trend are governed by the same general dynamics for both aspects of the 10° slope treatments. The 5° slope treatment linear trends are also similar for both aspects but they are different than the 10° slope treatments.

Significant linear deviations at the subsoil/spoil interface occurred for both aspects of the 10° slope treatments. Soluble sodium and SAR increased significantly from the spoil into the subsoil material (50 to 65 cm and 15 to 40 cm) in the upper slope position. These upper slope plots tended to be relatively drier at the soil surface than lower slope and 5° plots, indicating that soluble sodium is migrating

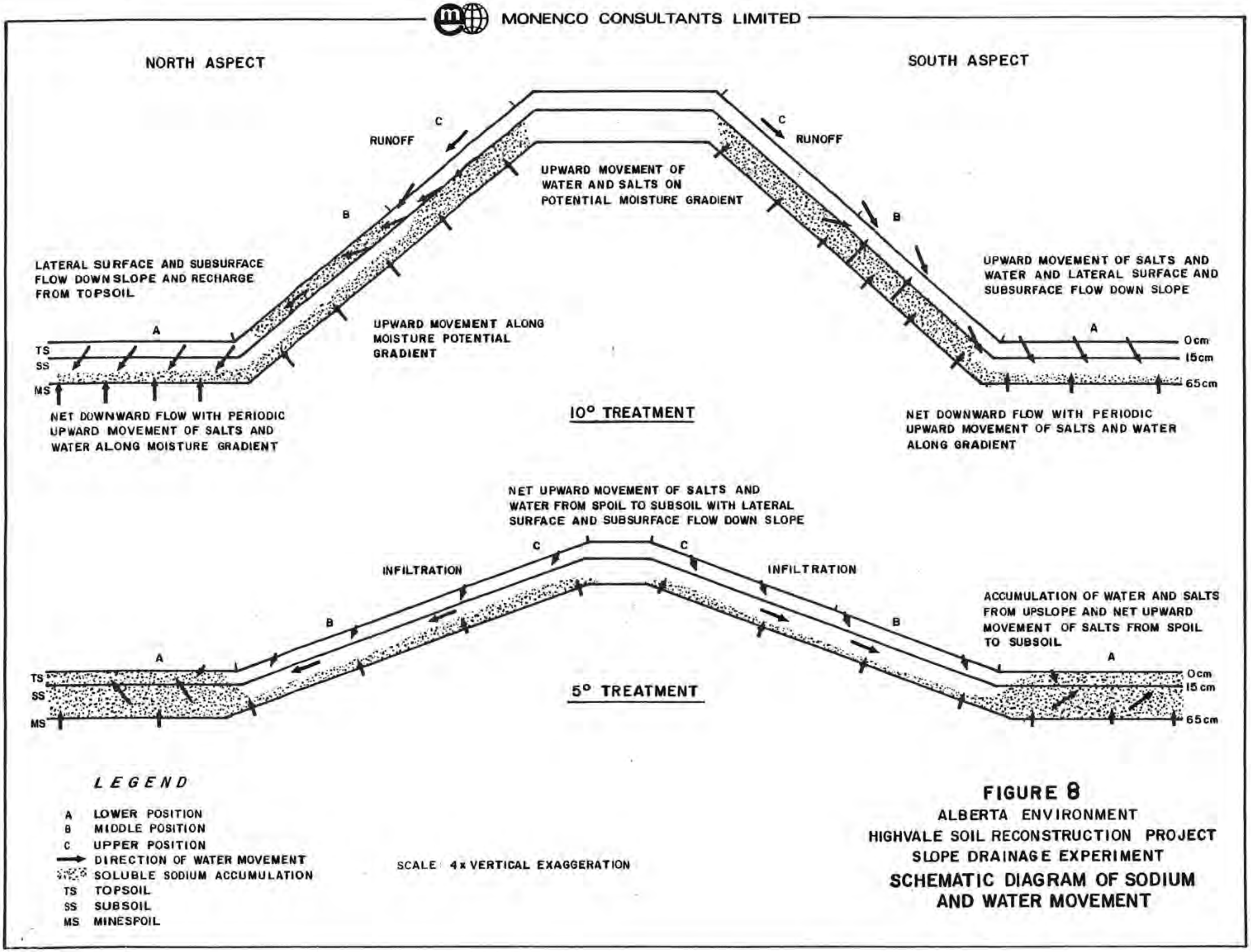


FIGURE 8
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SLOPE DRAINAGE EXPERIMENT
SCHEMATIC DIAGRAM OF SODIUM AND WATER MOVEMENT

upward from the spoil, either with capillary or diffusive movement of soil water in response to a potential moisture gradient at the soil surface. Review of the productivity data shows that yields were significantly higher on upper slope than lower slope positions. Thus, high evapotranspiration rates due to crop growth would enhance development of a potential gradient near the surface. It is unlikely that net downward movement of soil water occurs even periodically at the crest positions of the 10° slopes, due to high runoff and low infiltration rates.

Although the largest increases of soluble sodium and SAR from spoil into the subsoil have occurred in upper and mid-slope (10°N) positions, the net movement of soil moisture and sodium has been upward from spoil into subsoil at each position for the 10° plots. Soluble sodium, SAR and EC are all significantly higher at the interface than in the shallower subsoil intervals, and significant increases have occurred at the interfaces since 1982.

On the 10°S treatment, linear trend results for the 15-40 cm subsoil interval and for topsoil indicate significant increases of EC, soluble sodium and SAR at the midslope position. Increases in soluble sodium and SAR were also significant in topsoil at the midslope position of the 10°N treatment. This indicates a stronger net upward trend (from spoil to subsoil) on the south aspect than the north aspect slopes, which is expected since the moisture data showed that south aspect slopes were relatively dry compared to north aspect slopes.

The increased soluble sodium and SAR in the topsoil at the midslope position of the 10°N treatment probably represents accumulation and discharge of laterally moving subsurface water from upslope. Although some upward movement of salts from spoil to subsoil occurred at the interface, it did not extend into the upper subsoil, and additions of soluble salts to the topsoil in the middle position had to come by lateral movement from above. This suggests that soil water may be moving downslope along the topsoil/subsoil interface as well as the subsoil/spoil interface. The difference in bulk density between the topsoil (relatively low) and the subsoil (relatively high) may be sufficient to result in movement along the interface.

On the drier 10°S treatment, both upward migration of salts from the spoil along a potential moisture gradient and some lateral subsurface movement are probably occurring at the mid-slope position in the 15-40 cm subsoil interval.

It is interesting to note the differences between the north and south aspects on the 10° slope treatments. The higher evapotranspiration rate on the south aspect slopes results in more upward movement and less lateral movement than on north slopes where crop productivity was less and soil moisture greater throughout the profile. Thus, on south-facing slopes, sodium has increased at the interface, throughout the subsoil and somewhat in topsoil materials, while on north-facing slopes accumulation of soluble sodium is associated with only the interface and topsoil intervals.

The 5° slopes show less upward movement of sodium from the spoil into the upper zone (15-40 cm) of the subsoil and a greater accumulation of sodium in the lower slope position. Comparison of the interface subsoil sample (50-65 cm) and the 15-40 cm subsoil sample for each position by ANOVA also show that the soluble sodium has increased at the interface. The linear trend analysis did not show a significant slope effect related to upward movement of soluble sodium from the spoil at the interface because it occurred to the same extent at every slope position.

The upper slope positions of both north and south aspects of the 5° slope treatments are moister than their 10° slope counterparts. This results in a reduced potential moisture gradient toward the soil surface and less upward movement of sodium. It is also likely that the infiltration rate is higher on these more subtle slopes resulting in a greater potential for subsurface lateral flow at the spoil interface. The linear trends indicating accumulation of soluble sodium and higher SARs in the 15-40 cm subsoil interval and topsoil/spoil interface show that most of the increase is due to lateral (downslope) subsurface flow and not to upward movement.

Crop Productivity

Table 6 shows the means and standard deviations calculated for forage productivity by position, slope, aspect and combinations of those treatment factors. The table also shows the results of analysis of

TABLE 6

Productivity by Position, Aspect and Slope - Slope Drainage Experiment

TREATMENTS (Subsoil Depth) (cm)			PRODUCTIVITY - DRY BIOMASS (g/m^2) $\bar{x}$	sd	Pr > F (MODEL)*
POSITION					0.0001
Lower			734c**	305	
Middle			1440b	409	
Upper			1783a	408	
ASPECT					0.01
North			1158b	464	
South			1494a	619	
SLOPE					NS
10°			1209b	559	
5°			1442a	562	
ASPECT	POSITION				0.0001
North	Lower		669f	305	
	Middle		1214d	306	
	Upper		1589c	179	
South	Lower		838e	294	
	Middle		1667b	380	
	Upper		1976a	480	
ASPECT	SLOPE	(TREATMENT)			0.01
North	10°		1045d	219	
	5°		1270c	226	
South	10°		1374b	321	
	5°		1613a	367	
SLOPE	POSITION				0.0001
10°	Lower		675f	181	
	Middle		1245e	243	
	Upper		1709d	425	
5°	Lower		832c	362	
	Middle		1636b	337	
	Upper		1857a	253	
ASPECT	SLOPE	POSITION			0.0001
North	10°	Lower	655f	273	
		Middle	990e	191	
		Upper	1490d	194	
	5°	Lower	683f	360	
		Middle	1438c	221	
		Upper	1688b	97	
South	10°	Lower	695f	94	
		Middle	1500d	214	
		Upper	1927a	655	
	5°	Lower	982e	363	
		Middle	1833a	453	
		Upper	2025a	285	

*Results of ANOVA - Probability > F of model at 95% level.

**Results of Waller-Duncan K-ratio t-test - Numbers followed by different letters are significantly different at the 95% level.

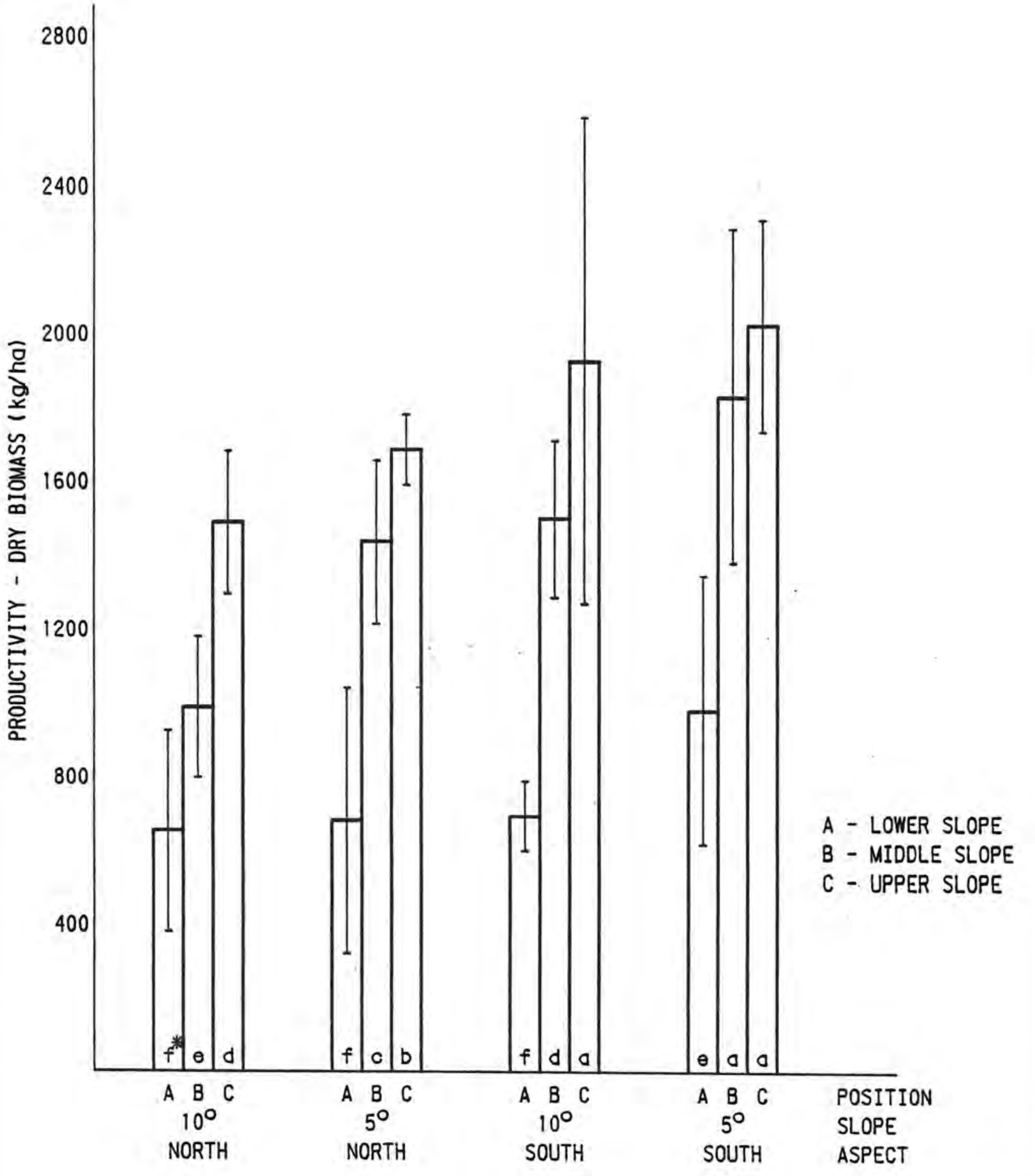
variance (PR> F) and the Waller-Duncan K-ratio t-test, both at 95% confidence. Results are also presented graphically for analysis by aspect, slope and position (Figure 9).

Significant differences in forage productivity were measured for all treatments and combinations except slope across all plots (PR> F = 0.0834). However, t-test results did show a significant difference across slope at the 95% level. Figure 9 shows the results of the paired comparison t-test by treatment (aspect and slope) and position. Lowest yields were measured on 10°S, 10°N and 5°N treatments all in the lower position. This indicates that lower position, regardless of degree of slope, is the worst case situation within the north aspect plots and that within the south aspect, both 10° slope and lower position result in reduced yields. Highest yields were measured within the south aspect plots. These results show that the strongest plant growth response is to upper slope positions in the south aspect.

CONCLUSIONS

Data from the first year's monitoring program indicates the following interim conclusions in the regard to the Subsoil Depth Experiment:

1. The null hypothesis that the subsoil/minespoil interface will not interfere with vertical water movement should be rejected.



*RESULTS OF T-TEST (PAIRED COMPARISON). BARS LABELLED WITH DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT THE 95% LEVEL.

FIGURE 9
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SLOPE DRAINAGE EXPERIMENT
1983 YIELDS
BY POSITION, SLOPE AND ASPECT

HG0489.CIIT

2. The null hypothesis that no sodium migration will occur should be rejected.

3. The null hypothesis regarding the lack of response of crop productivity to depth treatment and the similarity of the cereal and forage crop response should both be rejected. Maximum cereal yield occurred on the the 1.0 m treatment and maximum forage yield on the 0.5 m treatment, indicating that these are the optimal depths of subsoil for growth of these crops.

With regard to the Slope Drainage Experiment; the following interim conclusions can be made:

1. The null hypothesis regarding no slope effect on salt transport can be rejected.

2. The null hypothesis that crop productivity is not a function of slope treatments should be rejected.

3. Maximum yields were associated with upper slope positions and south aspects on the 5° slope plots.

It must be stressed that these conclusions are tentative, based only on one year's data, and may change as time goes on. Final conclusions and quantification of treatment effects will be reached after 5 years data has been collected and analysed.

ACKNOWLEDGEMENTS

Monenco Consultants Limited would like to acknowledge and thank all parties who have been involved in any manner on this research project. Special acknowledgements go to:

1. The Heritage Savings Trust Fund which provided financial support through the Land Conservation and Reclamation Council.

2. TransAlta Utilities Corporation who provided plot construction funds and ongoing maintenance of the area surrounding the site.

3. The Steering Committee and Plant-Soil Sub-Committee of the Reclamation Research Technical Advisory Committee for their continued guidance and assistance on all aspects of the project.

4. Alberta Environment's Research Management Division for their technical and project management support.

5. All advisors, especially those at the University of Alberta, including Dr. D. Chanasyk of the Department of Soil Science for the use of their facilities for calibration of the neutron probe and Dr. Z. Kondra of the Department of Plant Science for his input regarding seed and seeding methodologies.

The key Monenco personnel involved in this project were:

1. Mr. L.A. Panek - responsible for project management and administration.

2. Mr. T.A. Oddie - responsible for all "field" related agricultural activities.

3. Ms. M.M. Boehm - responsible for complete data base construction and statistical analyses.

4. Ms. V.E. Klaassen - responsible for moisture and bulk density analyses, data base construction and statistical analyses.

5. Dr. J.R. Dean - responsible for the laboratory analytical component.

6. Mr. E.C. Wenzel - responsible for "field" moisture monitoring and climatological data acquisition.

REFERENCES

Canada Soil Survey Committee. 1979. Canadian System of Soil Classification. Canada Department of Agriculture Publication 1646. Supply and Services Canada. Hull.

McKeague, J.A. (ed.). 1978. Manual on Soil Sampling and Methods of Analysis. Second Edition. Prepared by the Subcommittee on Methods of Analysis of the Canada Soil Survey Committee.

Nakayama, F.S. and R.J. Reginato. 1982. Simplifying Neutron Moisture Meter Calibration. Soil Science Volume 133, Number 1., p. 48.

SAS User's Guide. 1979. SAS Institute Inc. Statistical Analysis System. Gary, North Carolina.

BATTLE RIVER SOIL RECONSTRUCTION PROJECT: RESULTS THREE YEARS AFTER CONSTRUCTION

By

L. A. Leskiw[1]

ABSTRACT

The Battle River Reconstruction Project involves four (4) experiments designed to assess methods of reconstructing soil profiles in order to ameliorate the problems caused by the saline/sodic nature of the subsoils and bedrock.

The experiments assess soil reconstruction methods in terms of (a) varying subsoil depths; (b) separating and mixing subsoil horizons; (c) the use of bottom ash as a capillary barrier to salt movement; (d) altering the surface configuration (slope and aspect) of the reclaimed land; and (e) the use of gypsum and bottom ash as surface amendments. Yields from cereal and forage plots and soil salt and moisture movement have been monitored for 3 years. This paper discusses the results from the third growing season of the project.

This year's yields indicate that (a) forage production is more successful than cereal production; (b) topsoil is essential for reclamation; (c) increased subsoil depth results in higher yields and more favorable salinity and sodicity in the upper rooting zone; (d) bottom ash applied on the surface or above spoil increases forage production; and (e) gypsum applied at 20 T/ha helps to ameliorate the sodium problems that occur in reclamation of Torlea soils.

In 1983, a drought stressed season, it seems that crop yields were mainly determined by soil moisture supplying capability of the soils rather than soil chemical properties. Nevertheless, there is ample evidence of salt migration and continued monitoring will allow confirmation of trends.

[1] Pedology Consultants, Edmonton, Alberta.

INTRODUCTION

The Battle River Soil Reconstruction Project (BRSRP) was established in 1979 to determine the most effective methods of reclaiming lands disturbed by surface mining of coal in the Battle River Coal Fields. The Soil-Plant Subcommittee of the Plains Coal Reclamation Research Program defined the objectives, designed the experiments, and is supervising the on-going project. Funding for research activities is provided from the Alberta Heritage Savings Trust fund through the Alberta Land Conservation and Reclamation Council (Plains Coal Reclamation Research Program, PCRRP). Industry participants, namely, Alberta Power Ltd., Luscar Ltd., and Manalta Coal Ltd., funded initial construction activities, and continue to jointly manage the project through their membership on the Soil/Crop Subcommittee.

The project objectives are:

1. To determine the required depth of soil replacement over sodic mine spoil to ensure that mined land, particularly in the Battle River Coal Field, meets reclamation objectives. In this area, the reclamation objective is to return mined land to former levels of agricultural productivity.
2. To develop methods of sustaining re-established productivity, with emphasis on controlling salt movement from mine spoil into the reconstructed root zone.
3. To develop treatments which will minimize soil quantities needed to restore the original land productivity.

This project is located about 20 km north of Halkirk on lands transferred from Manalta Coal Ltd. to the County of Paintearth. The Project is comprised of four experiments situated within a fenced compound (Figure 1). The experiments are:

1. Subsoil Depth
2. Torlea Soil
3. Bottom Ash
4. Slope Drainage

The findings and opinions expressed in this paper are those of the author, and not of the Ministry of Alberta Environment or any of its representatives.

BACKGROUND

The dominant soils of the area before mining ranged from Dark Brown Solonetz to Orthic Dark Brown Chernozems developed on till deposits overlying the Horseshoe Canyon Formation. The topsoil and subsoil materials for the Subsoil Depth, Bottom Ash and Slope Drainage experiments were obtained locally from an area of Orthic Dark Brown Chernozemic and Dark Brown Solod soils. The soil materials used for the Torlea Soil Experiment originated from Dark Brown Solonetz soils which have significantly poorer chemical characteristics (Table 1).

Climate is continental with a frost-free period of approximately 100 days and an average annual precipitation of approximately 400 mm, 60 percent of which falls as rain during May through August.

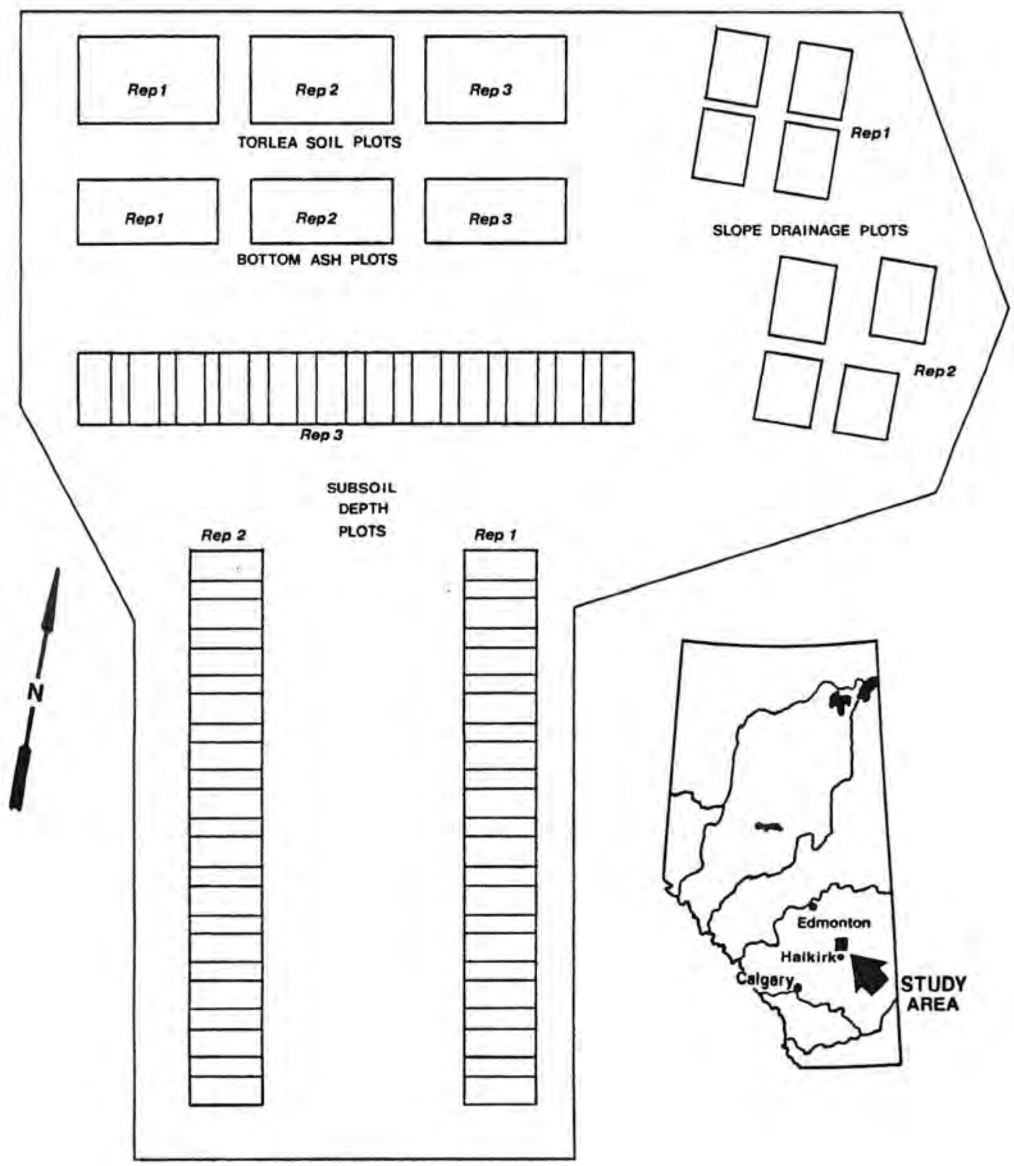


Figure 1. Location and Layout of Experiments.

Table 1. Chemical Analyses of Materials used in Plot Construction (Baseline conditions).

EXPERIMENT	MATERIAL	pH Mean	pH Standard Deviation	EC(mS/cm) Mean	EC(mS/cm) Standard Deviation	SAR Mean	SAR Standard Deviation	RECLAMATION SUITABILITY RATING[1]
Subsoil Depth	Topsoil	6.8	0.18	3.6	0.48	3.5	0.77	F(EC)
	Subsoil	7.8	0.10	5.8	0.67	8.4	1.60	F-P(EC;SAR)
	Spoil	8.0	0.14	2.9	1.00	23.9	2.73	U
Torlea Soil	Topsoil	7.7	0.10	2.4	1.00	13.5	1.25	U(SAR)
	Subsoil	7.4	0.28	5.7	1.33	14.2	1.65	U(SAR)
	Spoil	7.7	0.21	2.7	0.72	20.2	4.64	U(SAR)
	Ash	7.8	0.23	1.2	0.23	24.5	3.71	-
Bottom Ash	Topsoil	6.8	0.19	3.4	0.72	4.5	2.42	F(EC;SAR)
	Subsoil	7.6	0.12	5.5	0.86	8.5	2.86	F-P(EC;SAR)
	Spoil	7.7	0.25	2.7	0.63	22.7	3.60	U
Slope Drainage	Topsoil	6.8	0.39	3.5	1.49	5.9	4.16	F(EC)
	Subsoil	7.4	0.33	5.8	1.45	12.6	6.61	F-P(SAR)
	Spoil	7.9	0.18	2.8	0.30	24.0	1.67	U(SAR)

[1] Proposed Alberta Soil Quality Criteria (A.S.A.C., 1981)

Ratings	Constraints
F - Fair	EC - high electrical conductivity (salinity)
P - Poor	SAR - high sodium adsorption ratio (sodicity)
U - Unsuitable	

Topsoil: Topsoil is loam to clay loam textured A horizon removed from the native soils before mining.

Subsoil: Subsoil includes the B and C horizons plus underlying material that has chemical and physical properties suitable for sustaining vegetative growth.

Spoil: Spoil consists of sodic bedrock materials of the Horseshoe Canyon Formation.

Bottom Ash: Bottom Ash is the waste product of coal burnt at the Battle River Thermal Power Station. It is a sandy textured, pumice-like material characterized by relatively high calcium content and often toxic concentrations of boron.

Experimental plots were constructed in 1980 using mine machinery (dozers and scrapers) simulating the "take and put" system of mine reclamation (Parker, 1981).

On the plots, forage and cereal cropping practices are those commonly used by farmers in the area. Forage on the Slope Drainage plots was successfully established in 1981 and yields have been measured twice annually since. Forages on all other experiments were established in 1982 and yields were measured in the fall of 1982 and in the summer and fall of 1983. Wheat yields were measured in 1982 and 1983 on cereal plots within the Subsoil Depth and Bottom Ash experiments.

MONITORING ACTIVITIES AND METHODS

Crop and soil monitoring activities are conducted annually as part of the on-going study. The following procedures used in 1983 are similar or identical to those used in 1982, 1984 and planned for the future. Further details are given in the project quarterly and annual reports (Pedology Consultants, 1982, 1983, 1984).

CROP HUSBANDRY AND YIELD DETERMINATIONS

Agronomic activities on the cereal plots, during 1983, included preparing the seedbed (two cultivations and harrowing), broadcasting fertilizer (23-24-0) at a rate of 150 kg/ha, seeding Neepawa wheat at a rate of 100 kg/ha on April 30, hand spraying the plots with Hoegrass II and Torch, and harvesting on August 18.

Forage was established on the Slope Drainage Experiment in 1981 (Charlton bromegrass at 4 kg/ha and Beaver alfalfa at 16 kg/ha). The three other experiments were established in 1982 with Charlton bromegrass at 8 kg/ha and Rambler alfalfa at 15 kg/ha. In 1983, 150 kg/ha of 23-24-0 was broadcast on April 30. The first harvest was completed on July 20 and the second on September 21.

Forage yields are expressed on a dry weight basis (kg/ha) calculated from entire plot fresh weights measured in the field and subsamples dried to constant weight. Wheat yields in kg/ha were calculated from plot moist grain yields and subsamples dried for 24 hours at 60 degrees C.

SOIL MOISTURE MONITORING

Neutron probe access tubes were installed in all plots in 1982. A Campbell Scientific Subsoil Moisture Gauge, Model #503 was and is continuing to be used for monitoring soil moisture. Measurements are taken monthly, May through September.

SOIL BULK DENSITY MEASUREMENTS

A Campbell Scientific Model #501 moisture/density probe was used to measure soil bulk densities in all access tubes at various depths within the reconstruction materials. These measurements, conducted in May 1983, provide the first records of soil bulk density following construction of these plots.

SOIL FERTILITY

Soil samples were taken in early spring from forage and cereal plots to determine fertilizer requirements. Norwest Labs conducted the analyses and provided recommendations as for farmers. The recommendations serve as a guide to ensure that fertilizer applications meet minimum crop requirements for average yields.

SOIL SALINITY

The soils in each plot were sampled, in October, at 15 cm intervals to at least 50 cm into the underlying spoil. Chemical analyses included pH, EC (electrical conductivity, saturated paste), SAR (sodium adsorption ratio), saturation percent, soluble cations (Ca, Mg, Na, K) and soluble anions (SO_4, Cl), using standard analytical procedures (MacKeague, 1978). Results of 1983 soil analyses are summarized in the appended Tables (A1-4).

CLIMATE

A rainfall gauge was installed on the compound in 1983 and is being monitored by the Alberta Research Council. Figure 2 shows the weekly rainfall and corresponding crop calendar.

STATISTICAL ANALYSIS

Crop yields, soil electrical conductivities and sodium adsorption ratios were analyzed in detail for each experiment. In 1983, the Subsoil Depth and Slope Drainage experiments were analyzed as a randomized block design; Torlea and Bottom Ash experiments as split-plot designs.

For crop yield analysis, treatments and replicates were treated as fixed effects, and for soil analysis, treatments, replicates and crop type were assumed to be fixed. The treatment effects of primary interest for which there were a priori hypotheses were decomposed into orthogonal planned comparisons. For the Subsoil Depth and Bottom Ash experiments,

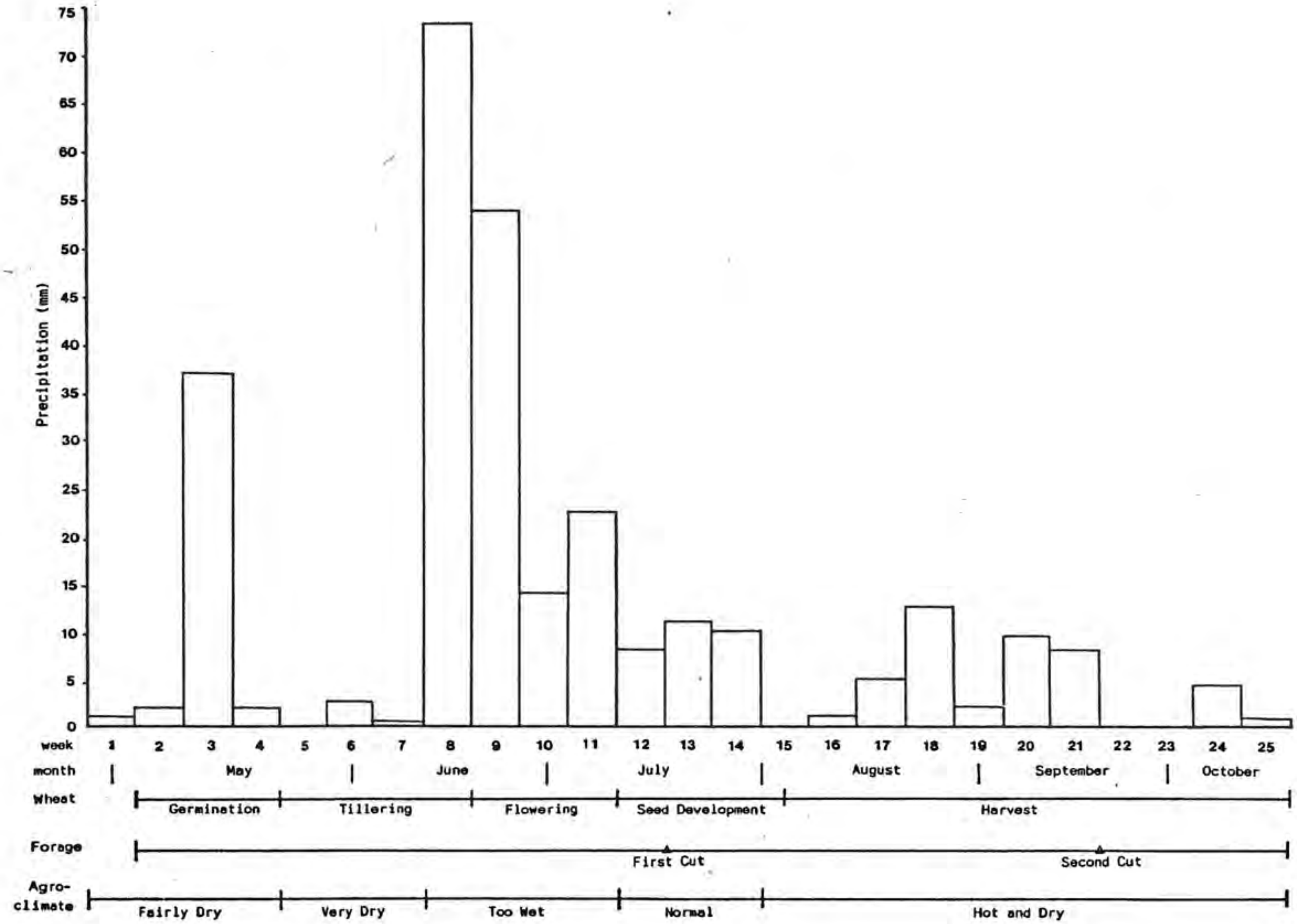


Figure 2. Weekly Precipitation Data - 1983 (April 27 - October 16).

the planned comparisons consisted of linear and quadratic trends over subsoil depth and deviations from those trends. For the other experiments, contrasts were also based on a priori hypotheses about treatment effects. Where trend analyses were conducted only, linear effects were found to be significant. For all analyses, the assumption of homogeneity of variance was tested with Bartlett's test and Hartley's test at $p = 0.05$ (Winer, pp. 200-210). All post-hoc tests were done with Tukey's HSD test at $p = 0.05$. (For specific statistical procedures concerning each experiment, the reader is referred to the 1983-84 Annual Report, Leskiw et.al., 1984.)

RESEARCH FINDINGS

A comprehensive analysis of yields, soil chemical and physical properties, and soil moisture levels revealed several important findings (Leskiw et.al., 1984). The major statistically significant ($p = 0.05$) results and important trends with respect to crop yields and soil EC and SAR are summarized for each experiment in the following sections. Soil moisture patterns and bulk density data are compared for all experiments.

SUBSOIL DEPTH EXPERIMENT

This experiment is designed to determine the optimum depth of replaced subsoil over sodic mine spoil required to sustain agricultural production. The following treatments are being assessed in relation to cereal and forage (2 cuts) production.

Treatment		
1	0 cm subsoil over spoil	10 cm topsoil covers all treatments
2	25 cm subsoil over spoil	
3	50 cm subsoil over spoil	
4	100 cm subsoil over spoil	
5	150 cm subsoil over spoil	
6	300 cm subsoil over spoil	

Yields

First and second cut forage crop yields, Figure 3, each increase linearly (statistically significant, $p = 0.05$) with increasing subsoil depth. This relationship probably reflects improving soil chemistry in the upper root zone, greater rooting depth and better moisture supply to the plants with increasing subsoil thickness. Roots are likely not penetrating the spoil due to physical or chemical constraints.

Wheat yields ranged from about 375 to 500 kg/ha and showed no response to treatments. These very low yields are attributed to climatic stress which was an over-riding factor in relation to soil limitations.

Soil Chemistry

Topsoil EC and SAR are higher under wheat than under forage crops (EC 3.2 > 2.5; SAR 3.2 > 2.2) but all values are below critical limits. These differences may be attributed to mechanical mixing by cultivation or to differences in moisture movement under different crops.

Upper subsoils are less saline (EC 5.5) than lower subsoils (EC 7.0). SAR in the upper subsoil decreases from 9.4 to 7.3 (significant trend) as subsoil depth increases from 25 to 300 cm. These findings may indicate that leaching is occurring in the upper subsoils or that sodium is moving upward from the spoil. The former implies that deeper subsoils enhance leaching; the latter suggests that shallower subsoils favor a rise of salts.

Spoil EC is higher under wheat (EC 6.1) than under forage (EC 4.8) but there are no significant differences or trends in SAR.

Treatment 1 (topsoil over spoil) is inferior to all other treatments (with subsoil). There is a clear trend of improving soil quality in the upper profile with increasing subsoil thickness and this is reflected in increasing crop yields. On the contrary, treatments with shallower subsoils may be degrading due to upward salt migration from the spoil. A qualitative (not tested statistically) comparison with original conditions following construction (Table 1) indicates that both processes may be occurring. For example, EC and SAR in topsoils and EC in upper subsoils have improved slightly over time. SAR in upper subsoils of the shallowest subsoil treatments have degraded while in treatments with deeper subsoil, the upper subsoils have improved.

TORLEA SOIL EXPERIMENT

This experiment assesses four methods of reclaiming lands mined from areas of Torlea Soil Series. The treatments tested in relation to forage (2 cuts) yields are:

Treatment

1	spoil
2	10 cm A/spoil
3	10 cm A/20 cm B+C/spoil
4	10 cm A/45 cm B+C/spoil
5	10 cm A/75 cm C/spoil
6	10 cm A/100 cm B+C/spoil
7	10 cm A/45 cm C/20 cm ash/spoil

Surface Amendment

Each reconstruction treatment has surface treatments as follows:

A - Bottom ash (15 cm of bottom ash contains exchangeable calcium approximately equivalent to a 20 T/ha application of gypsum

B - Gypsum (applied at 20 T/ha)

C - Control

Yield data are given in Figure 4.

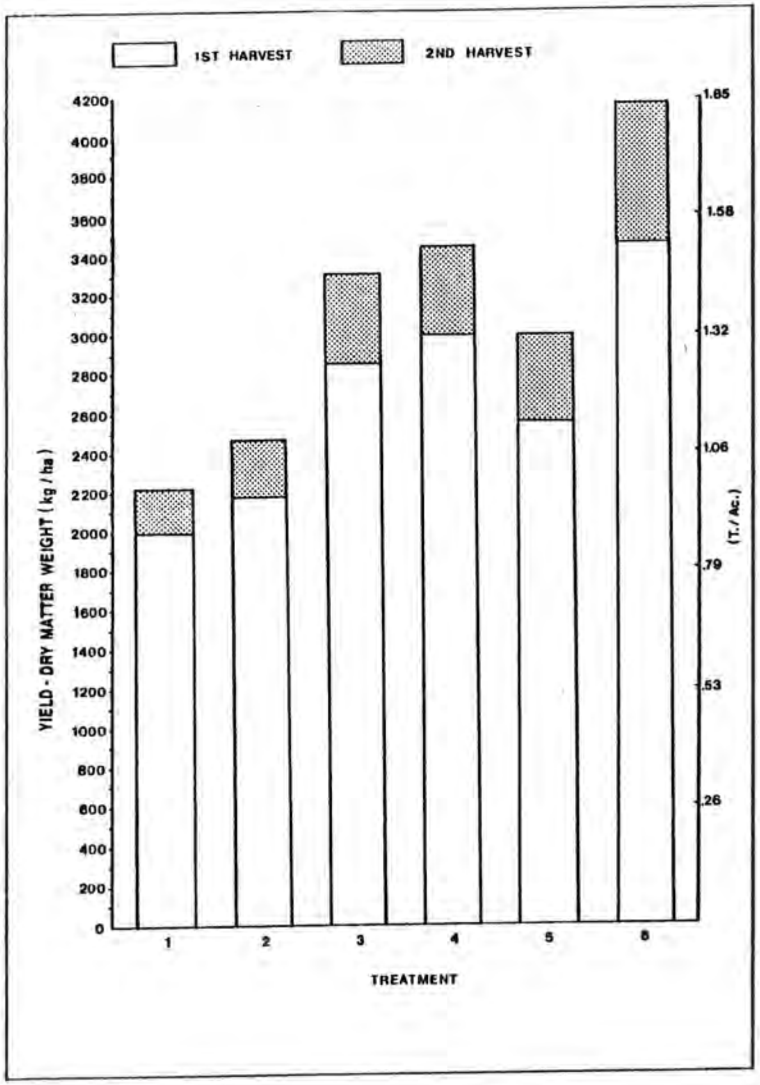


Figure 3. Subsoil Depth Experiment - 1983 forage yields.

Treatment	Soil Reconstruction
1	15 cm topsoil/spoil
2	15 cm topsoil/25 cm subsoil/spoil
3	15 cm topsoil/50 cm subsoil/spoil
4	15 cm topsoil/100 cm subsoil/spoil
5	15 cm topsoil/150 cm subsoil/spoil
6	15 cm topsoil/300 cm subsoil/spoil

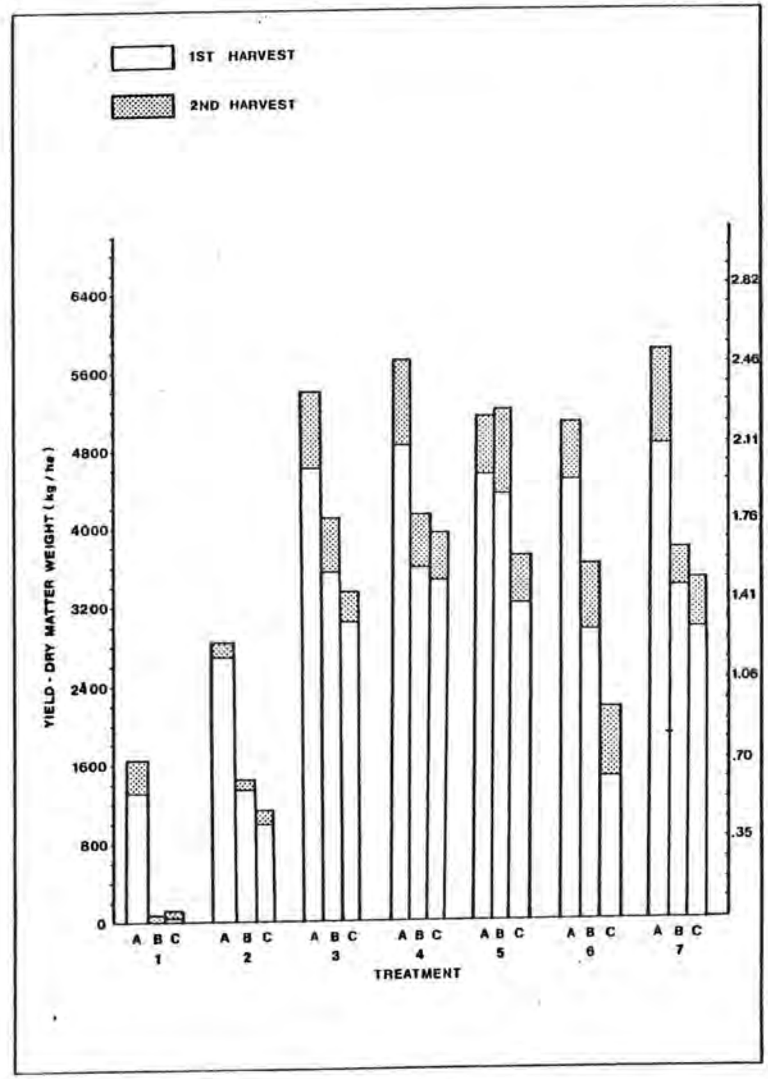


Figure 4. Torlea Soil Experiment - 1983 forage yields. A, B, and C respectively signify surface amendments of 15 cm of Ash, 20 T/ha gypsum and a control.

Treatment	Soil Reconstruction
1	Spoil
2	10 cm topsoil/spoil
3	10 cm topsoil/20 cm B and upper C horizons/spoil
4	10 cm topsoil/45 cm B and upper C horizons/spoil
5	10 cm topsoil/75 cm C horizon/spoil
6	10 cm topsoil/100 cm C horizon/spoil
7	10 cm topsoil/45 cm C horizon/20 cm Ash/spoil

Yields

Treatment 1 had a crop failure on gypsum and control plots and Treatment 2 yielded significantly less than Treatments 3 to 7. With respect to surface amendments, bottom ash yielded higher than gypsum which yielded higher than the control. These findings are applicable to both the first and second cuts even though yields of the latter are very low.

Soil Chemistry

Topsoil EC values are: ash (2.0) < control (3.5) < gypsum (5.0). Also Treatments 2 and 6 have higher EC than Treatment 3 (EC 4.4 and 4.6 > 2.0, respectively). SAR's in topsoils in the ash (10.2) and gypsum (9.7) treatments are lower than in the control (13.3). The foregoing findings are expected, except for the high topsoil EC in Treatment 6.

Upper subsoil EC in Treatment 7 (4.4) is less than in Treatment 3 (8.3) otherwise there are no significant differences even though the rankings produce an expected sequence. The low EC values in Treatment 7 indicate a positive effect of the subsurface ash layer. There is a significant trend relating subsoil depth to EC gradient within the subsoil layer. That is, there are greater differences between upper and lower EC values in deeper subsoil treatments regardless of composition of subsoil (C or B+C material). SAR in the upper subsoil is higher in the gypsum treatments (21.4) than in the ash (16.7) and control (17.0), and gypsum (20.7) is higher than control (17.0) in the lower subsoil.

In spoils there are considerable variances in both EC and SAR values but neither significant differences nor trends occur.

BOTTOM ASH EXPERIMENT

This experiment assesses the potential of bottom ash as a capillary barrier to upward movement of sodium salts from the underlying spoil. Forage (2 cuts) and wheat yields are tested on these treatments:

Treatment	
1	15 cm topsoil - 25 cm subsoil - spoil
2	15 cm topsoil - 25 cm subsoil - gypsum[1] - spoil
3	15 cm topsoil - 25 cm subsoil - 5 cm ash - spoil
4	15 cm topsoil - 25 cm subsoil - 15 cm ash[2] - spoil
5	15 cm topsoil - 25 cm subsoil - 45 cm ash - spoil

Notes:

[1] gypsum applied at 20 T/ha

[2] 15 cm of bottom ash contains exchangeable calcium approximately equivalent to a 20 T/ha application of gypsum

Yields are given in Figure 5.

Yields

Both forage harvests indicate a very significant ($p = 0.005$) yield increase corresponding to increasing thickness of ash. There is no difference in forage yields between gypsum and no-ash plots. As in the Subsoil Depth Experiment, wheat yields were very low and showed no significant variation with treatment.

Soil Chemistry

There are no differences among treatments in topsoil, subsoil and spoil EC levels. SAR's in topsoils are higher under wheat (5.1) than under forage (3.3), $p = 0.1$, but no significant differences occur at greater depths.

SLOPE DRAINAGE EXPERIMENT

This experiment is designed to determine the effect of landform (slope and aspect) on productivity through its influence on salt movement and accumulation. Forage yields (2 cuts) are determined for the upper, middle, and lower slope positions on the treatments (Figure 6) as follows:

Treatment	
1	5° - north aspect
2	10° - north aspect
3	5° - south aspect
4	10° - south aspect

Yields

First cut yields on 10° slopes south aspects were better than 10° slopes north aspects. No statistically significant differences occurred among other treatments in the first cut, and among all treatments in the second cut, even though yields were consistently higher in lower than in upper positions.

Soil Chemistry

Topsoil EC and SAR are higher in the lower position than in the middle and upper positions (EC lower, 3.1 > middle, 1.1 and upper, 1.0; SAR lower, 6.2 > middle, 3.7 and upper, 3.0).

Upper subsoil EC and SAR patterns correspond to those in the topsoil (EC lower, 8.4 > middle, 6.4 and upper, 6.1; SAR lower, 15.6 > middle, 12.9 and upper, 11.3).

Spoils have lower EC levels in the lower positions (EC lower, 4.8 < middle, 6.7 and upper, 7.0). EC and SAR values are greater on north than on south aspects.

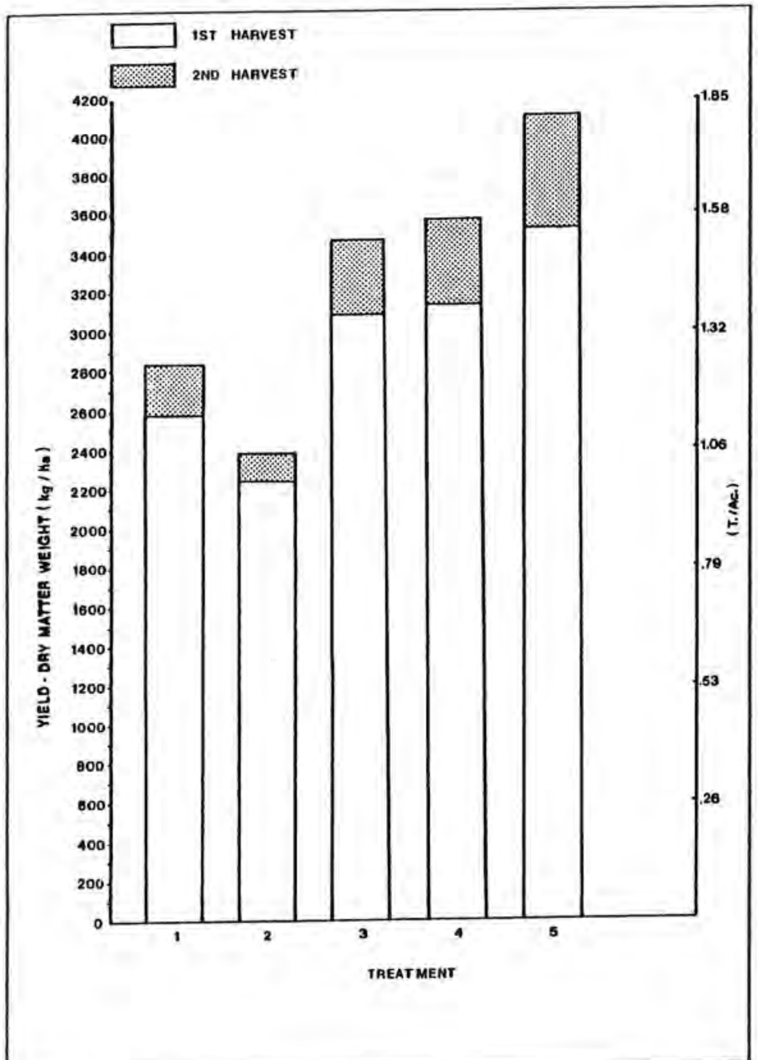


Figure 5. Bottom Ash Experiment - 1983 forage yields.

Treatment	Soil Reconstruction
1	15 cm topsoil/25 cm subsoil/spoil
2	15 cm topsoil/25 cm subsoil/gypsum (20 T/ha)/spoil
3	15 cm topsoil/25 cm subsoil 5 cm bottom ash/spoil
4	15 cm topsoil/25 cm subsoil/15 cm bottom ash/spoil
5	15 cm topsoil/25 cm subsoil/45 cm bottom ash/spoil

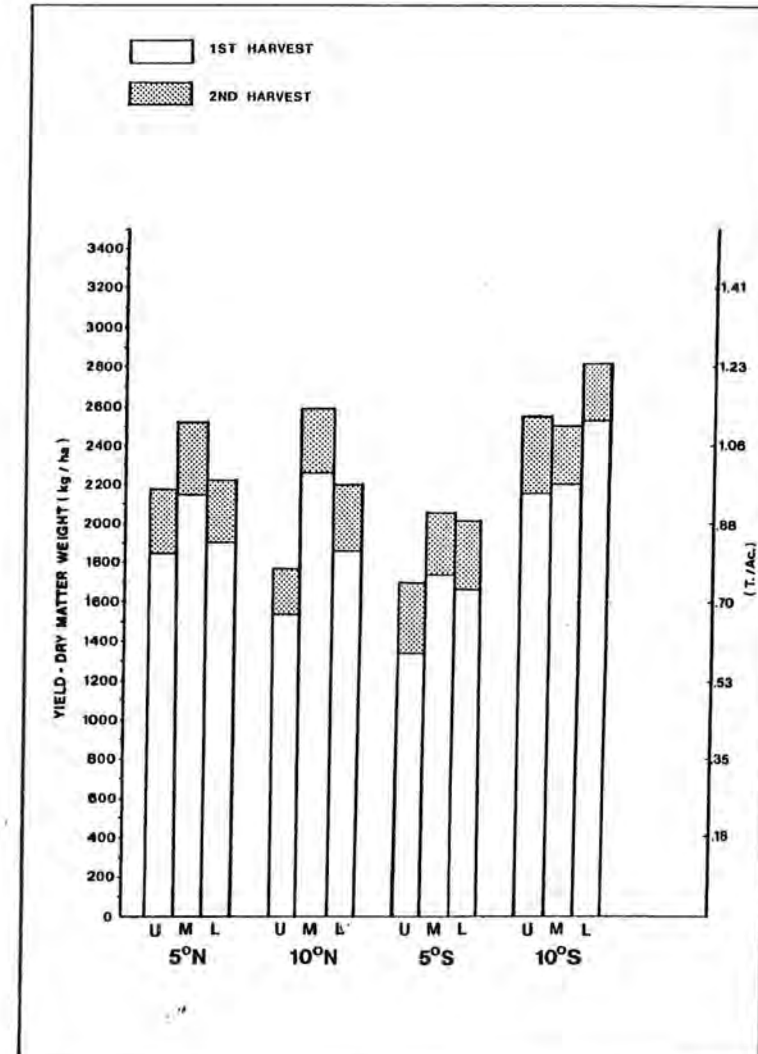


Figure 6. Slope Drainage Experiment - 1983 forage yields. U, M, and L signify upper, middle, and lower slopes, respectively.

ALL EXPERIMENTS

Soil Moisture

Soil moisture contents measured monthly with the neutron probe were converted to mm of water per specified depth of soil. Because of different reading levels among treatments and experiments, it is not possible to make direct comparisons, nevertheless, generalizations have been made for the 0-50 cm and 50-100 cm soil intervals. The following patterns apply to all experiments unless otherwise specified.

Soil moisture levels relate to rainfall distribution as shown in Figure 2. The sequence is:

May - June, moisture depletion - dry weather;

June - July, moisture recharge - heavy rains; and

July - September, moisture depletion - dry weather.

The greatest monthly changes in soil moisture occur in the 0-50 cm zone and slight changes occur in the 50-100 cm zone. Little fluctuation occurs at greater depths.

In comparing forage and wheat plots, the "slopes" of the depletion and recharge curves are generally steeper for forages than for wheat. "Steeper" depletion for forages relates to greater consumptive use. "Steeper" recharge suggests more rapid infiltration, less runoff, more moisture added to replace moisture withdrawn, or a combination of these. At all depths, forage plots tended to be drier throughout the season than wheat plots and the differences were magnified in the shallower zone (0-50 cm).

In the Torlea Soil Experiment, the ash treatments were usually driest followed by gypsum in Treatments 1 and 2 (no subsoil), and followed by control in Treatments 3 to 7 (varying depths of subsoil). Note that ash plots yielded highest.

In the Slope Drainage Experiment the upper positions are comparatively dry and the lower positions are moist, as expected. During the moisture depletion months, south aspects were drier than the north. The July moisture level peaks were similar in all treatments, however, the differences between upper, middle, and lower positions remained. This probably means that full recharge (saturation) did not occur, at least at the time of measurement.

The overall impression is that moisture availability in the rooting zone was more significant this drought stricken year than soil chemical properties. Spoil seems to prevent root and moisture penetration, as indicated by lack of fluctuation in moisture levels, hence, deeper subsoils with a larger rooting zone resulted in better yields.

Bulk Density

Topsoil, subsoil, and spoil materials each have similar densities for the Subsoil Depth, Bottom Ash and Slope Drainage experiments, Table 2. By comparison, Torlea soils have much lower densities in topsoil and subsoil and slightly lower densities in spoil. One possible reason for these differences is related to construction procedures: Torlea plots were completed in winter while others were completed in summer. If the materials were frozen or partially frozen, compaction could have been reduced. Differences in texture, moisture content during construction and soil structure of the source materials, and different handling procedures could also contribute to these differences

Table 2. Mean Bulk Densities of Materials for Different Experiments.

	EXPERIMENT			
	Subsoil Depth	Torlea Soil	Bottom Ash	Slope Drainage
	gm/cc*			
Topsoil	1.69	1.01	1.68	1.64
Subsoil	1.84	1.42	1.89	1.80
Spoil	1.56	1.37	1.55	1.56

* Measured with density probe in access tubes used for monitoring soil moisture.

since topsoils and subsoils for the Torlea plots were taken from a different place than for the other experiments.

SUMMARY AND CONCLUSIONS

The 1983 results represent the third cropping year for cereals after soil reconstruction. Forages were established on the Slope Drainage Experiment in 1981 and on the other experiments in 1982. The 1983 agricultural climate was characterized by a dry spring, a wet late June through mid-July, and a dry, hot fall. Crops suffered in early June and August resulting in average first cut forage yields but very low grain and second forage cut yields.

Plot construction was completed in the fall and early winter of 1980, therefore, soil moisture and salt movement had continued through three growing seasons at the time of soil sampling.

The following points represent the main findings to date, focussing on the 1983 growing season. Longer term monitoring is essential to confirm present findings and trends.

1. Subsoil Depth Experiment

   - There are no significant differences in forage or cereal yields between treatments, however, there is a significant linear trend indicating increasing forage yields (both cuts) with increasing subsoil thickness to 300 cm.
   - While salinity and sodicity remain below critical levels in the topsoils, the cereal plots are inferior to the forage plots. This is likely due to mechanical mixing of A horizon and subsoil material

with cultivation, upward salt migration or less leaching in the cereal plots.

- Upper subsoils tend to improve with increasing subsoil thickness.
- Upper spoils are inferior, with respect to salinity, under cereals as compared to forages.

2. Torlea Soil Experiment

- A lack of topsoil results in complete crop failure and topsoil over spoil results in very low crop yields -- both are unsatisfactory reclamation techniques.
- Application of 20 cm or more of subsoil, regardless of composition (C, B+C or C+ash), resulted in significantly higher yields.
- In terms of surface amendments, yields on ash are best, followed by gypsum, and control. Note that crop establishment on ash treatments was most difficult due to poor traction.
- Upper profile soil quality is unacceptable on Treatment 1, spoil only. Other treatments indicate that increasing subsoil thickness results in more leaching/less rise of salts in the upper subsoil.
- Ash surface treatments have superior quality with respect to EC and SAR in the topsoil and upper subsoil.

3. Bottom Ash Experiment

- There is a very significant relationship between forage yields and subsurface ash thickness: yields increase as ash thickness increases. Gypsum and control plot yields were similar.
- Soil salinity and sodicity in the upper profiles of gypsum and control plots are slightly more favorable than in the ash treatments.

- The higher yields on ash treatments are attributed mainly to higher root zone moisture supply.

4. Slope Drainage Experiment

- The first cut, south aspects yielded better than north aspects on 10° slopes, otherwise there were no significant differences in yields. This is attributed to more favorable soil temperature conditions early in the season.
- As expected, upper and middle slope positions have superior topsoil and upper subsoil quality as measured by EC and SAR.
- There is a tendency for north aspects to have higher EC and SAR values than south aspects. This suggests that higher yields on south aspects may also be attributed to more favorable soil chemistry. Lower positions would be expected to yield best but these generally have highest EC and SAR values.

5. All Experiments

Topsoil and at least some subsoil (20 cm+) is essential to reasonable crop growth. Yields tend to increase with increasing subsoil thickness but threshold or critical limits cannot be established on the basis of yields this year.

Moisture supplying capacity of the soils (with topsoil and subsoil) seems to be the over-riding factor in determining forage crop yields in 1983.

The application of bottom ash on the surface or between subsoil and spoil has very positive effects as reflected by crop yields.

Major fluctuations in soil moisture levels occur in the upper 50 cm or so of subsoil with minor fluctuations below. There is very little moisture change measured in the spoil.

6. Yearly Comparisons

To date, it is clear that salt migration is occurring. Also, it seems that a salt "bulge" (equivalent of Csa horizon) is beginning to form in many profiles. It tends to be more pronounced and shallower in shallower (<1 m) subsoil treatments than in deeper (>1 m) subsoil treatments.

Although this paper focuses on 1983 results, the objectives of this soil reconstruction study include comparing annual results to baseline conditions and monitoring changes over time. Plans are to present such preliminary results as part of the 1984/85 annual report.

REFERENCES

Alberta Soils Advisory Committee, 1981. Proposed Soil Quality Criteria in Relation to Disturbance and Reclamation. Alberta Agriculture.

MacKeague, J.A., 1978. Manual on soil sampling and methods of analysis. 2nd Ed., Can. Soc. Soil Sci.

Parker, R.W., 1981. Ash Studies in the Battle River Reclamation Research Project. Proceedings: Workshop on Coal Ash and Reclamation. Report #RRTAC 81-3. Alberta Land Conservation and Reclamation Council.

Pedology Consultants, 1982. Battle River Soil Reconstruction Project Quarterly Reports; June, September, December for 1982.

Pedology Consultants, 1983. Battle River Soil Reconstruction Project 1982/83 Annual Report.

Pedology Consultants, 1983. Battle River Soil Reconstruction Project Quarterly Reports; June, September, December for 1983.

Pedology Consultants, 1984. Battle River Soil Reconstruction Project 1983/84 Annual Report.

Winer, B.J., 1971. Statistical Principles in Experimental Design. McGraw Hill. New York.

Table A1. Chemical Analyses of Depth Intervals - Subsoil Depth Experiment.

			Cereal Plots								Forage Plots							
Reconstruction Treatment	Depth	Material	EC (mS/cm)		SAR		SAT %		Na (meq/l)		EC (mS/cm)		SAR		SAT. %		Na (meq/l)	
			x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd	x̄	sd
1. 0 cm	0-15	topsoil	3.3	0.8	3.7	1.6	32	2.7	17.1	6.0	2.8	1.1	2.0	1.1	34	2.2	9.3	6.5
	15-40	*spoil	5.9	1.7	18.6	5.7	76	27.0	56.3	15.2	7.3	2.7	16.0	3.5	68	9.2	66	23.0
	40-55	spoil	9.0	4.6	37.6	9.6	152	10.4	103.9	55.7	8.0	4.9	39.0	9.6	144	24.7	92.6	80.0
	105-120	spoil	6.6	1.9	39.4	4.3	159	8.4	69.8	23.4	4.4	1.0	33.0	6.6	173	23.3	43.0	13.9
2. 25 cm	0-15	topsoil	4.8	3.1	4.8	2.2	35	2.3	17.9	12.1	3.0	1.4	3.0	1.7	33	4.3	10.5	9.6
	15-40	subsoil	5.6	1.6	10.0	2.5	42	2.6	42.9	15.3	5.7	1.8	9.8	4.0	45	17.0	41.5	20.6
	40-55	*spoil	6.9	0.9	11.8	2.4	51	12.8	90.7	81.3	7.2	0.2	12.0	2.5	49	3.3	55.9	9.4
	105-120	spoil	5.0	0.6	32.3	4.4	168	6.5	48.4	12.0	5.7	2.0	31.6	10.2	146	33.9	56	26.4
3. 50 cm	0-15	topsoil	3.3	1.4	3.4	1.4	33	1.9	12.3	8.8	2.9	1.2	2.1	0.9	36	4.0	6.3	4.7
	15-40	subsoil	7.0	1.0	10.1	2.4	41	2.0	49.7	12.7	6.3	0.9	8.4	1.4	41	1.4	40.3	9.7
	50-65	subsoil	7.3	0.6	10.0	1.3	43	1.5	50.1	6.8	7.5	1.9	10.8	2.7	44	1.7	54.0	19.8
	65-80	*spoil	8.0	0.7	12.9	1.4	46	5.2	62.1	8.1	8.2	1.5	12.6	2.5	48	3.6	61.9	14.4
	130-145	spoil	5.5	1.6	37.3	14.5	162	6.6	59.0	25.7	4.5	1.4	28.9	7.4	190	14.6	40.3	16.4
4. 100 cm	0-15	topsoil	3.5	1.2	3.1	0.6	34	3.5	12.4	4.7	3.6	1.1	3.1	0.5	34	1.4	11.4	5.4
	15-30	subsoil	5.7	1.2	7.2	1.8	41	4.5	32.7	9.7	6.0	0.5	8.7	1.8	40	2.7	40.5	8.5
	50-65	subsoil	6.9	1.3	9.1	1.6	42	5.0	44.7	11.8	7.2	0.8	10.5	0.7	42	2.0	52.1	3.1
	85-100	subsoil	7.3	0.4	10.9	2.0	47	2.6	52.6	7.3	8.3	1.7	12.9	2.1	45	0.8	65.0	15.2
	100-115	subsoil	7.5	0.7	11.0	2.4	49	11.3	53.1	7.7	7.5	0.5	12.0	1.0	44	1.9	56.9	4.2
	115-170	*spoil	7.3	0.8	10.6	1.6	44	2.1	52.5	8.7	8.4	0.9	14.9	2.7	51	7.1	73.5	13.2
	180-195	spoil	6.8	1.2	33.8	4.5	145	5.5	67.9	13.6	5.0	1.4	29.6	7.5	160	19.2	47.2	16.7
5. 150 cm	0-15	topsoil	3.6	1.4	4.0	1.1	35	1.0	15.0	8.0	2.8	1.3	2.7	1.4	36	3.6	8.9	8.2
	15-30	subsoil	5.9	0.4	8.2	0.7	44	6.6	37.6	4.8	5.6	0.7	6.8	2.2	41	4.0	31.7	10.7
	50-65	subsoil	6.5	0.7	9.5	1.8	45	2.1	44.5	5.7	7.0	0.9	10.0	1.4	45	1.7	49.7	9.7
	85-100	subsoil	7.3	0.7	10.4	1.9	44	3.7	51.9	7.2	7.2	0.6	9.6	0.7	46	2.0	49.6	6.9
	120-135	subsoil	7.0	0.4	10.5	1.5	44	2.6	51.6	7.0	7.2	1.2	10.6	1.5	50	9.4	54	14.8
	135-150	subsoil	7.1	0.7	10.4	1.1	44	3.9	52.8	10.2	6.6	1.4	10.6	1.7	46	3.3	48.7	14.4
	150-165	subsoil	7.5	1.0	10.9	1.2	45	1.2	55.1	11.7	7.2	0.9	12.6	4.5	47	2.0	55.6	12.9
	165-180	*spoil	7.4	0.9	11.2	2.6	47	6.0	55.7	14.9	8.0	2.1	14.5	6.2	47	1.9	66.2	28.6
	230-245	spoil	6.9	1.9	26.8	8.9	129	44.6	145	21.2	6.0	3.0	35.6	20.7	147	23.4	63	41.2
6. 300 cm	0-15	topsoil	3.3	1.3	2.5	0.6	33	2	8.7	4.0	2.7	1.4	2.6	0.8	38	5.3	7.9	4.9
	15-30	subsoil	6.5	1.2	8.1	2.2	43	1.9	37.3	14.0	5.5	1.7	7.5	2.5	38	5.6	33.9	5.8
	50-65	subsoil	7.2	0.5	10.5	0.7	44	2.1	49.0	5.6	6.8	0.9	9.1	1.4	43	1.6	44.3	9.2
	85-100	subsoil	6.5	1.0	9.1	2.2	42	2.1	43.5	17.0	7.1	1.0	10.5	2.8	42	0.8	50	12.4
	120-135	subsoil	6.1	1.9	8.3	2.8	42	1.3	38.3	18.1	8.0	1.4	11.8	2.2	44	2.2	58.2	14.4
	155-170	subsoil	6.6	0.5	9.4	0.7	43	2.4	44.4	7.3	7.3	0.6	10.2	1.8	43	1.6	51.1	7.6
	190-205	subsoil	6.9	0.3	10.4	0.7	44	1.6	48.6	3.8	7.4	1.1	11.0	2.4	43	1.0	53.8	13.2
	225-240	subsoil	7.1	0.6	10.6	1.8	42	1.8	49.7	7.2	7.0	1.0	10.0	2.4	43	2.2	49.0	12.8
	260-275	subsoil	7.3	0.8	10.5	1.0	44	2.0	51	7.9	6.5	1.4	8.9	2.9	45	2.9	42.5	15.7
	285-300	subsoil	7.2	1.0	10.3	1.8	44	1.9	50.6	9.6	6.8	0.9	10.0	2.3	44	2.0	48.3	11.9
	300-315	subsoil	7.6	1.1	11.4	2.4	47	11.4	54.9	10.5	7.5	1.5	11.3	3.3	46	2.3	54.6	18.1
	315-330	*spoil	7.7	1.4	11.7	1.9	44	3.5	55.5	7.7	7.0	1.9	15.3	9.5	46	3.5	57.7	21.2
	380-395	spoil	8.4	2.1	21.2	6.9	102	41.0	73.6	14.9	4.9	1.7	29.2	14.2	172	40.7	43	16.1

Table A2. Chemical Analyses of Depth Intervals - Torlea Soil Experiment.

Reconstruction Treatment	Depth (cm)	Material	Ash Plots EC (mS/cm) x̄	sd	Na (meq/l) x̄	sd	SAR x̄	sd	SAT. % x̄	sd	Gypsum Plots EC (mS/cm) x̄	sd	Na (meq/l) x̄	sd	SAR x̄	sd	SAT. % x̄	sd	Control Plots EC (mS/cm) x̄	sd	Na (meq/l) x̄	sd	SAR x̄	sd	SAT. % x̄	sd
1. Spoil	0-15	spoil	3.7	1.74	41.6	25.3	31	11.8	118	55	10	4.08	118.4	50.7	36	3.7	139	13	5.1	2.55	57.9	32.7	33	12.4	160	17
	15-40	spoil	4.3	2.93	47.2	36.5	35	9.6	194	22	4.1	.77	44.9	11.9	33	5.5	175	11	3.4	.53	36.1	5.9	30	3.9	177	2
	80-95	spoil	5.1	2.24	57.8	26.7	38	1.9	168	19	3.0	.79	32.9	5.4	29	4.3	200	11	4.3	3.0	48.2	34.0	35	14.0	202	80
2. 10 cm A/ spoil	0-15	topsoil	3.3	1.27	33.9	15.8	19	5.8	83	24	6.5	.89	60	16.4	14	4.7	79	17	3.1	.57	31.3	7.0	16	7.0	93	36
	15-40	spoil	3.5	1.43	32.6	17.4	25	4.1	182	25	3.7	1.05	40.8	13.7	30	4.2	179	12	5.0	2.36	56.9	28.0	33	7.5	179	25
	80-95	spoil	6.0	4.33	61.6	40.7	31	4.4	168	37	4.6	1.29	52.4	18.1	42	6.6	182	5	3.1	1.09	35.4	14.3	31	6.1	201	27
3. 10 cm A/ 20 cm B + C/ spoil	0-15	topsoil	.9	.16	6.4	4.2	4	3.1	51	3	3.5	1.62	24.6	12.9	6	1.9	62	2	1.6	.11	16.0	1.9	9	1.3	70	4
	15-40	B+upper C	5.9	2.07	56.5	19.7	15	1.2	78	5	9.3	2.19	98.7	27.3	24	6.3	95	14	8.0	1.93	76.2	11.3	15	1.1	76	1
	40-55	spoil	5.5	1.10	60.4	5.5	25	6.5	142	26	3.9	1.86	42.2	21.2	31	6.8	188	35	10	2.41	30.1	38.1	44	9.5	141	15
	105-120	spoil	5.3	3.35	59.1	40.7	36	17.1	183	33	4.5	3.83	48.1	43.7	37	20.5	199	31	4.9	2.53	50.4	28.1	31	4.3	179	9
4. 10 cm A/ 45 cm B + C/ spoil	0-15	topsoil	1.2	.51	9.7	5.3	6	2.8	55	6	3.6	1.64	26.6	17.1	7	3.9	62	6	1.8	.30	17.5	2.2	9	1.7	69	3
	15-30	B+upper C	4.5	1.57	46.1	16.7	15	3.5	72	3	7.6	2.44	73.4	22.6	15	1.9	72	1	5.0	1.79	49.1	18.3	14	1.0	74	2
	30-50	B+upper C	5.8	2.00	61.7	23.0	19	5.7	79	7	9.6	.73	92.9	7.2	20	8.7	81	20	8.9	.21	83.7	6.5	15	1.5	76	7
	50-65	spoil	9.1	.85	87.7	9.2	19	5.0	92	25	4.3	3.49	45.5	34.2	23	4.5	157	83	8.1	1.97	83.1	10.4	28	12.1	132	31
	115-130	spoil	4.3	.54	46.6	8.1	38	3.6	160	22	5.9	3.94	65.3	44.3	38	16.5	209	64	4.9	2.83	54.5	32.2	34	10.0	179	32
5. 10 cm A/ 75 cm C/ spoil	0-15	topsoil	1.9	1.26	21.7	16.3	11	7.3	58	5	4.0	.59	21.6	10.9	4	2.5	60	.5	6.3	2.38	60.9	21.1	17	2.9	81	15
	15-30	C horizon	5.5	2.85	55.9	22.6	18	5.1	92	21	6.8	1.97	68.1	13.6	18	1.5	97	10	5.8	5.06	59.8	47.4	17	5.9	86	21
	30-45	C	7.3	4.37	68.5	38.9	17	.5	115	45	8.9	.56	89.7	7.0	19	.7	106	17	8.4	2.75	83.8	18.4	21	3.6	95	17
	45-60	C	7.4	2.99	76.0	25.5	20	3.7	103	20	7.6	1.04	80.7	13.8	22	1.1	102	18	7.9	1.39	78.5	6.2	19	6.1	85	20
	60-75	C	6.4	4.08	63.0	38.9	17	1.7	110	39	10	1.22	100.5	15.1	19	.7	87	11	7.1	2.05	70.6	16.0	18	4.4	95	10
	75-90	C	5.8	2.11	62.9	13.1	25	9.3	140	22	8.9	.61	89.5	7.9	18	1.6	95	13	6.5	2.71	60.2	27.0	18	6.3	118	45
	140-155	spoil	4.6	3.02	50.6	36.7	41	14.5	189	45	5.8	3.77	66.6	43.0	38	18.9	179	61	4.1	1.74	44.6	23.0	33	7.7	204	28
6. 10 cm A/ 100 cm B + C/ spoil	0-15	topsoil	2.7	1.87	28	19.7	12	3.6	69	14	6.8	.55	61.4	10.0	13	1.7	71	3	4.0	2.10	38.2	18.4	12	1.8	72	3
	15-30	B + C	6.3	.99	65.1	3.9	21	7.8	103	25	10	1.33	112.3	19.6	21	3.6	86	2	7.4	1.28	72	10	17	1.3	93	14
	30-45	B + C	7.4	1.56	76.5	10.6	21	5.6	102	16	6.9	2.53	68.2	24.3	19	3.5	108	23	8.3	.92	85.1	7.2	22	5.4	102	15
	45-60	B + C	6.9	2.70	71.2	26.8	21	5.8	109	32	8.1	2.01	81.9	20.9	18	.4	93	10	7.2	2.13	73.7	20.4	19	2.4	98	4
	60-75	B + C	8.2	.90	83.6	11.1	17	2.2	79	15	7.9	1.22	76.8	12.0	17	2.1	86	3	7.5	2.29	74.0	16.0	18	3.9	85	21
	75-100	B + C	9.5	.69	93.0	12.1	17	2.7	80	13	8.1	1.22	80.5	9.7	16	1.5	79	7	7.6	.26	74.0	7.2	15	2.4	67	5
	100-115	spoil	6.4	1.75	74.8	19.5	40	2.6	144	8	6.6	1.85	77.5	25.0	32	3.5	139	31	9.3	4.05	04.3	42.3	35	3.3	132	33
	165-180	spoil	8.5	4.43	101	54.1	41	5.7	153	50	3.4	.37	35.3	2.8	30	3.4	184	19	6.8	3.07	74.8	34.9	32	10.1	139	32
7. 10 cmA/ 45 cm C/ 20 cm Ash/ spoil	0-15	topsoil	1.4	.35	11.0	2.1	6	2.0	56	2	5.0	2.48	45.4	26.0	12	5.8	70	9	4.2	2.06	42	21.2	15	3.6	80	16
	15-30	C horizon	3.0	1.36	31.0	15.3	16	4.4	97	21	5.3	1.06	58.2	13.6	24	3.0	121	15	4.7	2.09	48.8	24.7	18	6.7	121	21
	30-50	C horizon	7.3	.44	74.5	2.1	21	4.6	103	16	7.9	2.25	87.6	26.6	24	6.6	103	21	5.4	2.79	53.1	23.4	18	2.1	112	39
	50-65	ash	7.5	1.01	70.5	4.1	17	2.1	90	12	8.6	1.13	89.2	19.8	19	4.1	85	9	6.9	.48	67.8	4.4	17	3.5	93	18
	115-130	spoil	5.5	2.84	55.6	27.3	28	9.4	147	50	5.4	2.09	60.3	22.6	34	7.7	161	23	5.6	2.84	61.2	30.5	32	7.2	170	19

Table A3. Chemical Analyses of Depth Intervals - Bottom Ash Experiment.

RECONSTRUCTION TREATMENT	DEPTH (cm)	MATERIAL	CEREAL PLOTS EC (mS/cm) x̄	sd	SAR x̄	sd	SAT. % x̄	sd	Na (meq/l) x̄	sd	FORAGE PLOTS EC (mS/cm) x̄	sd	SAR x̄	sd	SAT. % x̄	sd	Na (meq/l) x̄	sd
1. Control	0-15	topsoil	2.9	1.6	3.7	1.3	36	2.6	14.2	9.5	2.6	2.2	2.9	2.9	35	3.6	12.2	15.1
	15-40	subsoil	6.2	0.6	9.1	1.8	41	2.0	43.6	7.3	6.4	2.9	9.8	7.2	46	19.5	46.5	34.3
	40-55	spoil	5.3	0.1	27.9	3.3	135	31.0	58.7	1.3	7.4	0.6	40.5	6.8	155	43.8	79.8	4.6
2. Gypsum	0-15	topsoil	4.2	1.8	6.6	3.1	34	3.5	27.4	15.7	2.0	1.9	2.9	2.2	36	4.6	10.2	11.4
	15-40	subsoil	8.9	1.9	16.5	3.8	51	6.1	77.4	19.6	5.8	2.5	10.0	4.3	43	8.9	44.9	24.8
	40-55	spoil	6.5	1.8	29.6	11.8	78	15.6	88.5	38.7	6.9	3.5	17.4	2.4	105	76	60.7	26.8
3. 5 cm of Ash	0-15	topsoil	3.8	2.9	5.7	4.1	37	4.9	23.8	23.8	3.2	1.5	4.2	1.2	35	3.2	16.5	8.5
	15-40	subsoil	7.6	2.4	12.2	4.3	43	2.6	33.2	31.8	8.2	1.2	13.4	3.3	44	0.6	66.7	13.9
	40-55	spoil	12.6	-	55.2	-	159	-	149	-	6.2	1.0	33.7	7.6	127	3.0	67.9	14.8
4. 15 cm of Ash	0-15	topsoil	4.4	1.8	4.8	5.2	36	4.2	21.9	23.2	3.3	1.0	4.1	1.8	36	6.4	14.6	0.6
	15-40	subsoil	7.3	1.4	12.1	3.3	45	5.0	57.6	14.5	8.3	1.6	12.9	3.7	46	6.2	66.3	18.6
	40-55	ash	1.9	0.1	8.0	5.4	61	18.3	13.0	5.1	3.2	1.5	12.0	5.1	59	12.7	27.5	5.2
5. 45 cm of Ash	0-15	topsoil	3.6	2.3	4.5	4.7	38	4.5	19.8	22.1	2.7	0.8	2.3	1.2	35	0.6	8.4	2.9
	15-40	subsoil	4.4	1.5	7.5	1.7	43	6.6	28.5	9.8	8.7	4.1	16.2	10.4	41	6.5	83.4	61.8
	40-55	ash	1.7	0.8	7.3	0.7	58	13.0	12.1	4.0	5.0	2.7	12.8	10.9	53	15.4	40.5	41.7
	60-85	spoil	5.8	-	39.1	-	150	-	59.6	-	7.4	-	37.3	-	94	-	82.6	-

Table A4. Chemical Analyses of Depth Intervals - Slope Drainage Experiment.

			Upper Slope								Middle Slope								Lower Slope							
Reconstruction Treatment	Depth (cm)	Material	EC (mS/cm) x̄	EC (mS/cm) sd	Na (meq/l) x̄	Na (meq/l) sd	SAR x̄	SAR sd	SAT. % x̄	SAT. % sd	EC (mS/cm) x̄	EC (mS/cm) sd	Na (meq/l) x̄	Na (meq/l) sd	SAR x̄	SAR sd	SAT. % x̄	SAT. % sd	EC (mS/cm) x̄	EC (mS/cm) sd	Na (meq/l) x̄	Na (meq/l) sd	SAR x̄	SAR sd	SAT. % x̄	SAT. % sd
1. 5° - N	0-15	topsoil	1.1	.59	5.1	5.2	2	2.5	32	1	.7	.26	3.3	.9	2	.5	35	3	2.7	1.43	19.1	12.9	6	4.5	47	12
	15-40	subsoil	6.6	3.22	55.1	37.9	12	7.7	40	7	4.4	3.78	36.1	35.8	9	6.6	36	8	8.1	2.98	96.1	72.2	15	7.9	55	17
	50-65	subsoil	8.9	2.56	86.7	31.1	21	9.6	74	51	7.6	2.26	74.3	17.9	21	4.8	67	9	5.4	2.10	59.6	24.2	38	8.4	158	28
	65-80	spoil	10.0	1.70	116	25.7	47	10.5	135	39	7.4	2.55	79.4	22.0	36	6.2	151	14	7.5	2.67	81.3	26.4	38	6.2	151	51
	130-145	spoil	7.1	1.21	79.9	13.8	40	5.3	138	39	5.5	1.52	61.5	14.7	36	3.7	166	31	5.1	3.17	52	32.9	30	3.0	156	28
2. 10° - N	0-15	topsoil	2.9	2.75	16.9	25.9	2	1.5	37	9	1.5	.29	9.4	1.2	4	1.0	32	4	4.2	3.57	32.3	37.8	8	7.6	41	7
	15-40	subsoil	6.7	3.13	55.3	30.9	12	6.1	53	19	8.5	2.62	72.3	20.6	16	.9	49	2	8.4	2.17	73.2	24.9	15	5.3	45	4
	50-65	subsoil	9.1	3.76	85.8	42.1	18	6.6	80	63	7.8	1.23	60.9	11.9	13	4.2	54	23	5.5	4.52	51.4	36.8	22	4.4	162	79
	65-80	spoil	7.2	4.21	62.6	37.5	23	6.8	68	48	5.0	1.01	52.4	14.6	30	8.1	163	19	6.9	1.58	69.5	11.8	24	5.1	148	18
	130-145	spoil	7.8	1.93	75.8	13.4	33	6.2	134	57	7.2	2.21	74.1	17.9	30	4.5	160	15	6.2	1.61	64.3	13.9	28	4.6	147	7
3. 5° - S	0-15	topsoil	.9	.57	5.8	3.0	4	3.2	32	1	.9	.78	6.8	5.6	4	1.6	32	2	2.2	2.59	15.0	20.7	4	3.8	35	4
	15-40	subsoil	5.8	2.10	49.1	22.5	12	4.4	40	7	6.0	3.31	53.6	32.1	13	5.7	40	12	8.1	1.05	67.2	10.1	14	2.2	42	3
	50-65	subsoil	7.3	4.11	67.9	41.5	15	7.3	50	6	8.5	3.12	80.2	31.5	17	4.2	47	8	6.7	2.36	64.7	18.9	26	6.1	*372	503
	65-80	spoil	8.0	2.88	78.3	21.6	26	8.6	111	73	10.7	2.30	106.7	22.3	30	4.7	109	45	5.6	2.35	56.0	23.9	28	5.2	403	510
	130-145	spoil	6.9	1.71	77.5	20.6	39	5.5	156	8	6.7	1.86	73.9	23.0	38	10	165	13	9.1	2.75	95.1	29.5	44	11.6	412	496
4. 10° - S	0-15	topsoil	.6	.23	3.9	2.0	2	1.3	30	.9	1.3	.66	6.3	4.7	3	2.2	33	3	3.2	1.79	18.1	13.4	4	2.5	42	8
	15-40	subsoil	4.6	1.03	32.8	10.0	8	2.7	34	2	6.4	1.54	48.6	18.7	12	6.0	50	16	8.8	2.10	73.5	17.8	16	3.8	48	5
	50-65	subsoil	6.6	2.36	58.6	20.5	18	6.4	84	59	4.9	3.02	38.8	25.8	10	2.8	43	3	4.6	3.14	43.2	29.0	24	3.0	141	33
	65-80	spoil	4.2	.87	41.2	8.4	27	1.3	157	17	3.7	1.70	38.1	19.0	26	8.0	159	23	2.8	.90	27.1	11.3	25	2.7	164	31
	130-145	spoil	5.3	2.09	56.1	25.1	36	10.6	181	22	3.9	.72	39.5	6.4	28	3.2	159	18	3.8	.72	38.9	11.6	26	5.1	152	33

Note* material at the 50-65 cm depth interval, in the lower slope position is actually spoil.

GAS RESEARCH INSTITUTE PIPELINE RIGHT-OF-WAY RESEARCH ACTIVITIES

Cindy A. Cahill, Gas Research Institute

Ralph P. Carter, Argonne National Laboratory

ABSTRACT

A research program was initiated in early 1983 to conduct selected field and laboratory research activities which will provide the natural gas transmission industry with cost-effective options with which to mitigate ecological impacts and minimize restoration costs of pipeline installation and maintenance. The program is based upon the results of a survey of 20 gas transmission companies to define needed environmental research associated with construction and maintenance of gas transmission pipelines. The assessment study identified five areas in which research could benefit the industry: 1) evaluating soil erosion control techniques; 2) monitoring recovery of streams following pipeline installation; 3) monitoring recovery of agricultural lands; 4) documentation of successful reclamation; and 5) development of a selective bibliography of literature relative to disturbance caused by pipeline installation. To date, two field research projects have begun in conjunction with gas transmission line construction, and the bibliography completed. A project has been initiated to monitor construction impacts of a pipeline stream crossing in central Ohio. A second project to monitor crop yields and edaphic changes following pipeline construction is underway in northern Oklahoma. Finally, a project to investigate methods to reduce erosion and improve soil/slope stability along pipeline rights-of-way is in the planning stages.

INTRODUCTION

The Gas Research Institute* (GRI) Pipeline Right-of-Way Research Program was established in response to needs voiced by the natural gas transmission industry for quantitative data on the restoration of pipeline rights-of-way. The objectives of this program are to develop cost-effective options which will mitigate ecological impacts and minimize costs associated with pipeline installation and maintenance by conducting selected laboratory and field research projects. The program is being conducted by Argonne National Laboratory.

Typical large diameter gas transmission pipeline construction begins with the clearing of a right-of-way between 75 to 100 feet wide. Ditching machines dig a trench and the pipe sections are placed next to it. Welders connect the pipe into a continuous length; the outside surface of the pipe is then cleaned, coated, and wrapped to prevent corrosion. Finally, the pipe is lowered into the trench, and the trench is backfilled. Rivers can be crossed using one of five techniques, depending upon stream width, depth, and flow: 1) wet ditch or open trench; 2) aerial or bridge crossings; 3) flume or bypass technique; 4) directional drilling beneath the river; and 5) plow or sled technique. These construction practices have the potential to result in a myriad of

---

*GRI is an independent, not-for-profit scientific research organization which plans, funds, and manages research for the benefit of the natural gas industry and the consumer.

environmental impacts. Terrestrial plant and animal habitats may be temporarily disturbed or permanently altered. The trenching operation, heavy machinery, and lack of vegetation cover may cause increased soil erosion and sedimentation into rivers and streams. Heavy machinery may also cause soil compaction, making it difficult for vegetation to become reestablished. Finally, river crossings may result in river bank and bottom erosion, significant downstream impacts such as increased sedimentation, and temporary disruption of invertebrate and fish populations.

The research program is based upon results of a survey of twenty gas transmission companies to define common environmental research needs related to construction and maintenance of gas transmission pipelines. The assessment study identified the need for more data in the following research areas:

1) Improved soil erosion control techniques;
2) Monitor effects of pipeline construction on river aquatic systems;
3) Monitor recovery of agricultural lands following pipeline construction;
4) Documentation of successful right-of-way (ROW) reclamation; and
5) Selective bibliography of literature related to disturbance caused by pipeline installation.

To date, the computerized literature review has been completed and two of the field research projects have begun in conjunction with gas transmission line construction. The third field project, soil erosion control, is in the planning stages.

A. Soil Erosion Control

The primary objective of this research area is to identify and evaluate alternative nonvegetative methods to reduce erosion and improve soil/slope stability along pipeline ROWs. The investigations will also determine the magnitude of change in erosion rates resulting from pipeline installation, relate observed changes to site conditions, and quantitatively evaluate the effectiveness of selected mitigative measures in reducing erosion losses. More specifically, field projects will be designed to: identify and review available engineered control structures for reducing runoff and erosion; identify and review available chemical agents (soil conditioners) which alter soil-water relationships for reduced runoff and erosion and increased soil stability; evaluate the applicability of alternative erosion control strategies in terms of specific site conditions known to be related to erosion phenomena (e.g., soil characteristics, slope, precipitation); and demonstrate the relative effectiveness of selected erosion control techniques under laboratory and field conditions.

A tentative research site has been identified on a 24" diameter gas transmission pipeline that will be constructed in southwestern Pennsylvania by Consolidated Gas Supply Corporation. A wide range of new erosion control methods, including both vegetative (Beatty, 1982) and nonvegetative will be evaluated to determine which can be tested on the steep (22%) right-of-way slope. Construction of the pipeline is scheduled for September 1984 and it is expected that field test plots will be in place during October. Preliminary results will be available in the first quarter of 1986.

B. Effects on Pipeline Construction on River Aquatic Systems

The goal of this research area is to obtain quantitative information on the nature and magnitude of impacts to aquatic ecosystems caused by disturbances from pipeline construction and the rate at which various ecosystem components recover after construction is completed. A field project is being conducted at a crossing of the Little Miami River in the Glen Helen Nature preserve near Yellow Springs, Ohio. The Little Miami River is one of 32 scenic rivers designated by the Federal Government and the first scenic river in Ohio. Columbia Gas System Service Corporation completed the crossing during October, 1983. To provide quantitative information, GRI is monitoring water quality (e.g., specific conductance, suspended sediment, temperature, dissolved oxygen) in addition to biological communities (fish and benthos) before and after pipeline construction at several stations upstream and downstream of the construction site to determine cause-effect relationships, if impacts to aquatic organisms are observed.

Monitoring from October, 1983 through April, 1984 show that silt and sand were found to accumulate on the streambed within 100 m downstream of the crossing site. Concentrations of suspended solids, generally less than 20 mg/L prior to construction, increased to a maximum of 843 mg/L during construction. Suspended solids generally decreased to below 50 mg/L within 2 hours following trenching activities (Figure 1). No detrimental alterations of water chemistry as a result of pipeline construction were observed. Benthic invertebrate densities and species composition were typical of stream pools with low densities compared to riffles. Post-construction collections indicated that benthic recolonization of the affected areas occurred within two months. In addition, a productive riffle which is located approximately one mile downstream showed no decreases in densities following construction. Habitat conditions also limited the fish community in the area, with the silver shiner being the predominant species. Post-construction collections revealed that the silver shiner had recolonized the affected stream reach. However, densities and size distributions both decreased at, and below, the crossing. Seasonal effects, especially those related to food-resource availability, were deemed largely accountable for the variations observed in fish distributions. Overall, construction-associated impacts on benthos and fish were minimal. Final results will be available in the spring of 1985.

C. Recovery of Agricultural Lands Following Pipeline Construction

The goal of this research area is to develop data that can be used by the gas transmission industry to accurately predict the time required for ecosystems to recover from the disturbances caused by pipeline construction. The influence of typical pipeline construction methods and ROW reclamation techniques on the rate and success of the reclamation process will be evaluated by monitoring the establishment, persistence, and productivity of naturally colonized, as well as seeded, vegetative communities, together with related edaphic changes in typical agro-ecosystems.

A field project was initiated in Beaver County Oklahoma where Panhandle Eastern Pipe Line Company installed a new transmission line using the single-ditch method typical of pipeline installation operations in the region. Four study sites were selected representing four major land uses in Beaver County; wheat, both dry land and irrigated, grain sorghum and pasture. An experimental design was developed for each site by establishing a linear sampling pattern to monitor soil parameters and crop production after construction. Three separate parallel sampling transects were established directly over the pipe (P), intermediate (I) area where construction traffic has occurred and a control (C) transect at the edge of the right-of-way that is unaffected by construction activities. At five points on each of the three transects, soil samples are being collected and neutron probe access tubes have been installed to monitor soil moisture and bulk density at several elevations. In addition, vegetation samples are being collected at 10 locations on each transect using the circular quadrat method (Kennedy, 1972).

Preliminary results of six months field sampling show that soil bulk density of samples from the pipe ditch was significantly lower than that of samples from the other transects. No significant differences were found between the trafficked-transect (I) and the control-transect (C) samples. Soil bases (i.e., Ca, Mg, Na, K), pH, total phosphorus, and electrical conductance of the pipe-ditch (P) samples reflect the inherent characteristics of the subsoils of the adjacent transects [i.e., trafficked (I) and control (C)] with all sample values being within the accepted range for crop production. Monitoring is expected to continue on this project for 1-2 additional years.

D. Documentation of Successful Reclamation

It is well known within the gas transmission industry that successful reclamation of pipeline ROWs following construction can be accomplished. However, quantitative documentation is not available to provide evidence to regulatory personnel that successful reclamation can be accomplished. The objective of this project is to identify and collect field data from existing pipeline rights-of-way in a singular sampling event, and document specific cases of successful reclamation activities accomplished by transmission companies.

GRI and Argonne are working closely with seven transmission companies to sample vegetation on ROWs in various parts of the country. For each site selected, a systematic sampling procedure is used. Three transects are set up on the right-of-way: (P) over the pipe or where maximum soil disturbance occurred caused by the trenching operation; (I) the intermediate area or working side of the pipeline where construction traffic occurred, but soil was not removed; and (C) the control transect just off the ROW unaffected by construction activities. Five vegetation samples are collected along each of the transects using the same method described in the revegetation/edaphic study. The samples are dried and weighed to determine differences in productivity between the transects. Biomass productivity from the disturbed sites is compared to undisturbed areas to determine the success of the reclamation techniques used. Information is also collected on climate, soil type, vegetation, and rehabilitation methods to reclaim the ROW. This information will provide semi-quantitative data in a relatively short period of time for transmission companies to use with permit applications as supporting evidence that successful reclamation is achievable.

E. Selective Bibliography

A comprehensive review of the literature relevant to the reclamation of disturbed lands has been compiled into a computerized database (Bluth, 1984). The contents of the database includes information on aquatic and terrestrial impacts and mitigative strategies for pipeline corridors, as well as electric transmission line, railroad, and highway rights-of-way.

The computerized literature review was compiled by searching a total of twenty existing databases for 66 key words related to reclamation of disturbed lands, especially pipeline rights-of-way. The information from each database search was screened as received to determine the applicability to the overall program. Only the data of direct value to the projects in the Pipeline Right-of-Way (ROW) Program were entered into the database. Each entry contains the complete information for locating a reference, in addition to an abstract.

The transmission industry is utilizing the database when writing soil erosion control plans and environmental assessments, and in preparing permit applications for a construction project, and as supporting evidence when responding to questions posed by permitting agencies related to revegetation, impacts on streams, or soil compaction. Information from this database is also being utilized by the ROW Program to ensure that no duplication of work is conducted, and as supporting work for results from this program.

SUMMARY

GRI is pleased with the support and participation exhibited by the transmission industry on this program. A steering committee has been established to assist with selection, site evaluation, and review of research projects to assure relevance to industry needs. The companies are benefitting from the development of a database of ROW reclamation research information which is being utilized by the industry to respond to questions raised by permitting agencies. An additional direct benefit is that disturbed lands will be returned to full productivity in a minimum of time.

REFERENCES

Beatty, M.T. (1982) Soil Erosion: Its Agricultural, Environmental & Socioeconomic Implications, Council for Agricultural Science and Technology, Report No. 92, Jan. 1982.

Bluth, M. (1984) A Selective Bibliography on the Reclamation of Natural Gas Transmission Pipeline Rights-of-Way, GRI Report GRI-84/0100, July 1984.

Kennedy, R.K. (1972) The Sickledrat: A Circular Quadrat Modification Useful in Crossland Studies, Journal of Range Management, 25(4), pp 212-213.

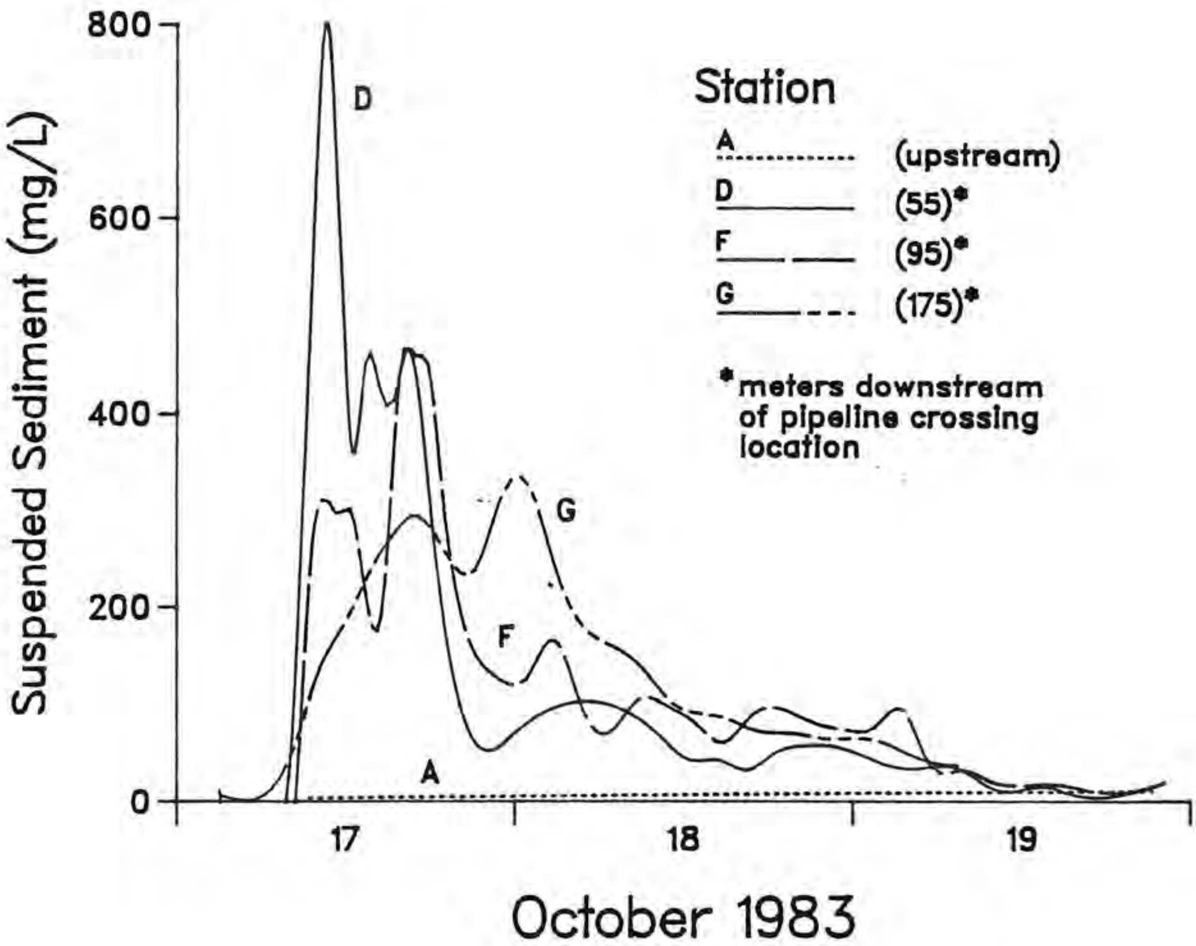


Figure 1. Suspended Sediment at Downstream Stations During Trenching Operations. Little Miami River, OH.

SUBSOILING TO MITIGATE COMPACTION

ON THE

NORTH BAY SHORTCUT PROJECT

Walter H. Watt
TransCanada PipeLines Limited

Abstract

In 1982, TransCanada PipeLines Limited constructed a 426 km, 914 mm diameter natural gas pipeline in new right-of-way between North Bay and Morrisburg, Ontario. The pipe installation was complete by December 1982, but clean-up of approximately two-thirds of the route was postponed until the spring of 1983. During construction, compaction of subsoil along the working side of the right-of-way was recognized as a serious concern and subsoiling was recommended as a mitigative measure. This paper explains how the extent of the compaction problem was determined, describes the type of tillage equipment used and evaluates the degree of success achieved.

Introduction

In returning lands disturbed by construction to productive agricultural use, it is necessary to deal with the problem of soil compaction. Compacted soils exhibit impaired soil structure (decreasing aeration) slower infiltration (leading to ponding or surface erosion), and restricted rooting volumes (increasing susceptibility of plants to nutrient or moisture stress). All of these factors may contribute to reduced crop yields, particularly in abnormally wet or dry years.

Compaction resulting from pipeline construction is a recognized environmental concern (e.g. Sheilds et al 1979) especially in fine-textured soils or where construction is allowed to proceed under wet conditions. Only recently, though, have concerted efforts been made to evaluate the extent and degree of compaction on particular projects and soil types. Environmental inspection of construction, coupled with post-construction monitoring has helped to focus attention on subsoil compaction at depths greater than 40 cm and has resulted in efforts to mitigate this compaction (e.g. TransCanada 1982). Moncrieff et al (1983) have reported on research to evaluate deep subsoiling as a restoration measure some years after construction in a very severe - and fortunately atypical - situation. The present paper describes the efforts of TransCanada to integrate subsoiling into its conventional clean-up activities on the North Bay Shortcut project, and comments on the results achieved.

The Project

In 1982, TransCanada constructed a 426 km, 914 mm diameter pipeline in new right-of-way between North Bay and Morrisburg, Ontario. Though nearly half of the route was in rocky Canadian Shield terrain and though efforts were made to avoid agricultural land during route selection (Hare *et al* 1984), about 170 km of farmland was crossed, most of it on Spread 3, between Pembroke and Morrisburg. While pipe installation was complete by December 1982, most clean-up in agricultural land was postponed until 1983. Despite favorable weather and soil conditions for construction and clean-up, subsoil compaction on this project went from a predicted impact, to a demonstrable phenomenon, to an equipment problem, to a logistical challenge. Solving the problems and meeting the challenge resulted in an excellent clean-up job and hopefully a minimum of compaction-related crop losses in 1984.

Demonstrating Compaction

The environmental assessment report for this project (TransCanada 1980) identified compaction of the right-of-way as a serious concern and suggested that specialized heavy cultivation equipment might be necessary to loosen compacted soils.

As clean-up commenced in 1982, it became apparent that the conventional equipment being used - a chisel cultivator - could not satisfactorily loosen compacted subsoil without overworking it and further degrading the structure (TransCanada 1983a). But when the cultivator was replaced with a road grader carrying five ripper teeth on a hydraulic tool bar, it became necessary to seriously investigate the degree of mitigation being achieved. On coarser textured pasture or forest soils, the grader/ripper turned out to be quite satisfactory, but on finer-textured, cultivated soils, its average working depth (25cm) was found to be insufficient and the design and arrangement of its teeth were unable to provide the lifting action desirable for shattering compacted layers. Moreover, the weight of the grader combined with wheel-slip to re-compact the subsoil as stock-piled topsoil was re-spread. Thus, probing the soil with a core sampler on transects across the right-of-way yielded the result shown in Table 1, and bulk density measurements confirmed that the degree of compaction was a potential problem for root penetration. Residual compaction was thus demonstrably present on the right-of-way.

In the fall of 1982 and again in the spring of 1983, penetrometer, bulk density and infiltration measurements were taken at several depths in test pits on and off the right-of-way to see whether frost action would alleviate compaction. It was found to have little effect, supporting the recommendation for deep tillage.

<u>Subsoiling Equipment</u>

In order to select suitable tillage equipment, however, it was necessary to know the average and maximum depths of compaction and the areal extent of the problem.

It was possible to rule out subsoiling on some sections of the right-of-way for obvious reasons, where the land was forested or abandoned roughland pasture; where the water table was within subsoiling depth year round; where the land was excessively stony; or where shallow, systematic tile drainage was an unavoidable obstacle.

TABLE 1: Depth of Compaction (maximum penetration of core sampler) in Fall 1982

Location +	Average depth of penetration*	
Off right-of-way	45	a
Topsoil Stockpile	34	b
Spoil Stockpile	31	b
Workspace	25	c
Workspace	24	c
Off right-of-way	45	a

+ samples taken in transects of 6 points across right-of-way

* average over 8 properties sampled; means followed by same letter are not significantly different at the 1% level by Duncan's New Multiple Range Test

On remaining portions of the right-of-way, probing could establish the relative ease of penetration and the depth to the compacted layer, but this would not tell how deep the compaction went or how penetration by the probe correlated with penetration by plant roots. A preliminary survey was therefore undertaken to establish the correlation of bulk density with cone penetrometer readings (soil strength) over the range of soil textures encountered. Given the reasonably good correlation (r^2=0.71), penetrometer readings were taken as an acceptable indicator of compaction and the right-of-way was systematically sampled, taking readings at four depths up to 60 cm. In addition, bulk density measurements were taken at representative locations in each of six soil series. The results (see Figures 2 and 3 for examples) suggested a fairly universal zone of compaction on the working side of the right-of-way, extending to a depth of 40 or 50 cm, and often in a fairly distinct layer at 40 to 45 cm. The contractor was asked to provide an appropriate implement and obtained one (the Kello-Bilt Series "5000" Subsoiler) which was rugged and capable of working depths up to 65 cm. In addition, its five parabolic shanks were mounted on a V-frame and spaced at 50 cm intervals to reduce draft and to shatter pans without inverting the profile.

Flexible Specifications

Given the pseudo-experimental nature of what we were attempting, flexibility was necessarily a key component of the subsoiling specifications developed for this job. To make the field adjustments required by flexible specifications, TransCanada relied on the cooperation of its contractors and on the collective skills of equipment operators, construction inspectors and consultants. From the outset, there were three practical objections to the subsoiling recommendation, the first being stone. Because a significant proportion of the right-of-way was underlain

FIGURE 2 · Soil Density Comparison of Workspace and Control Areas *

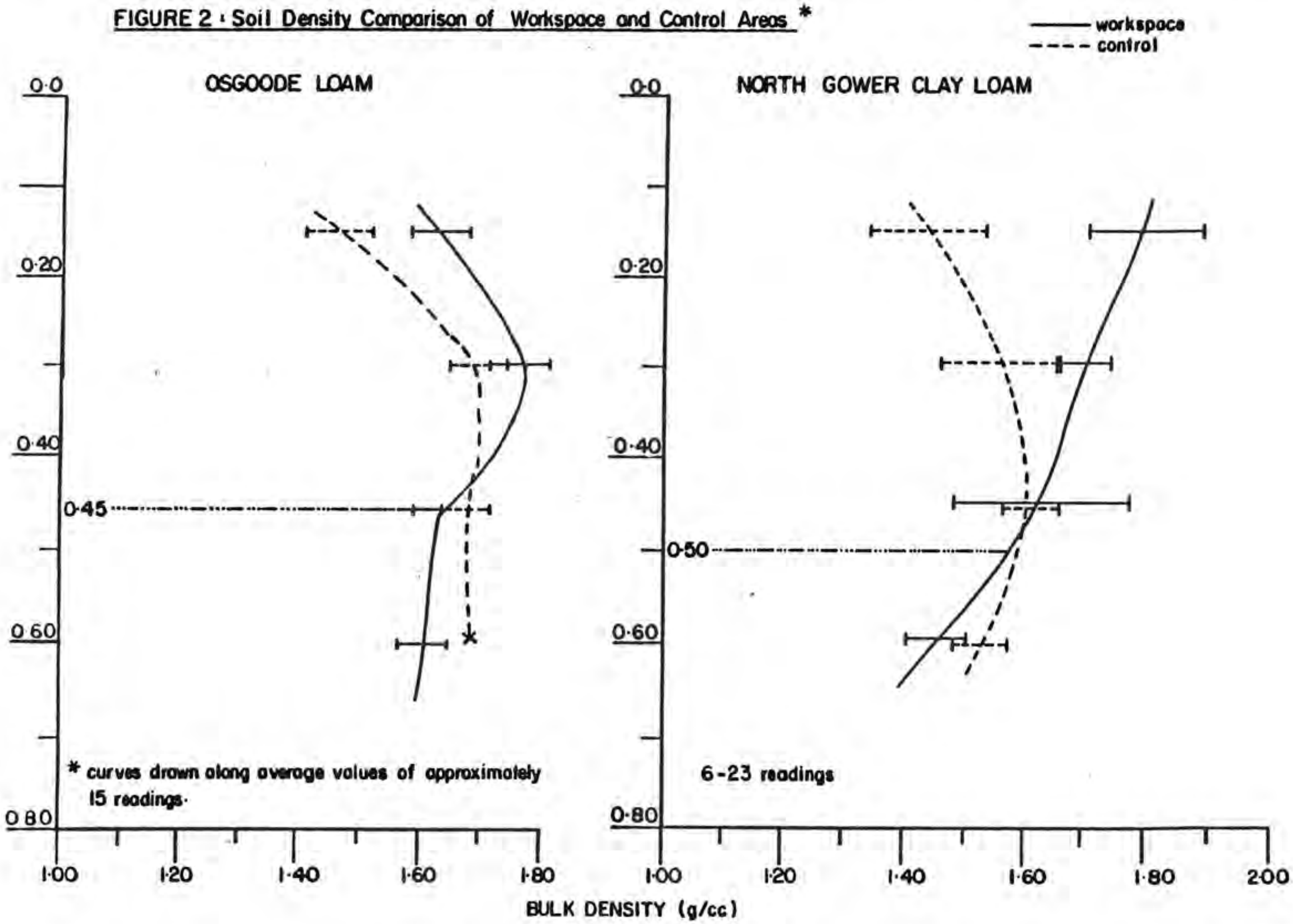
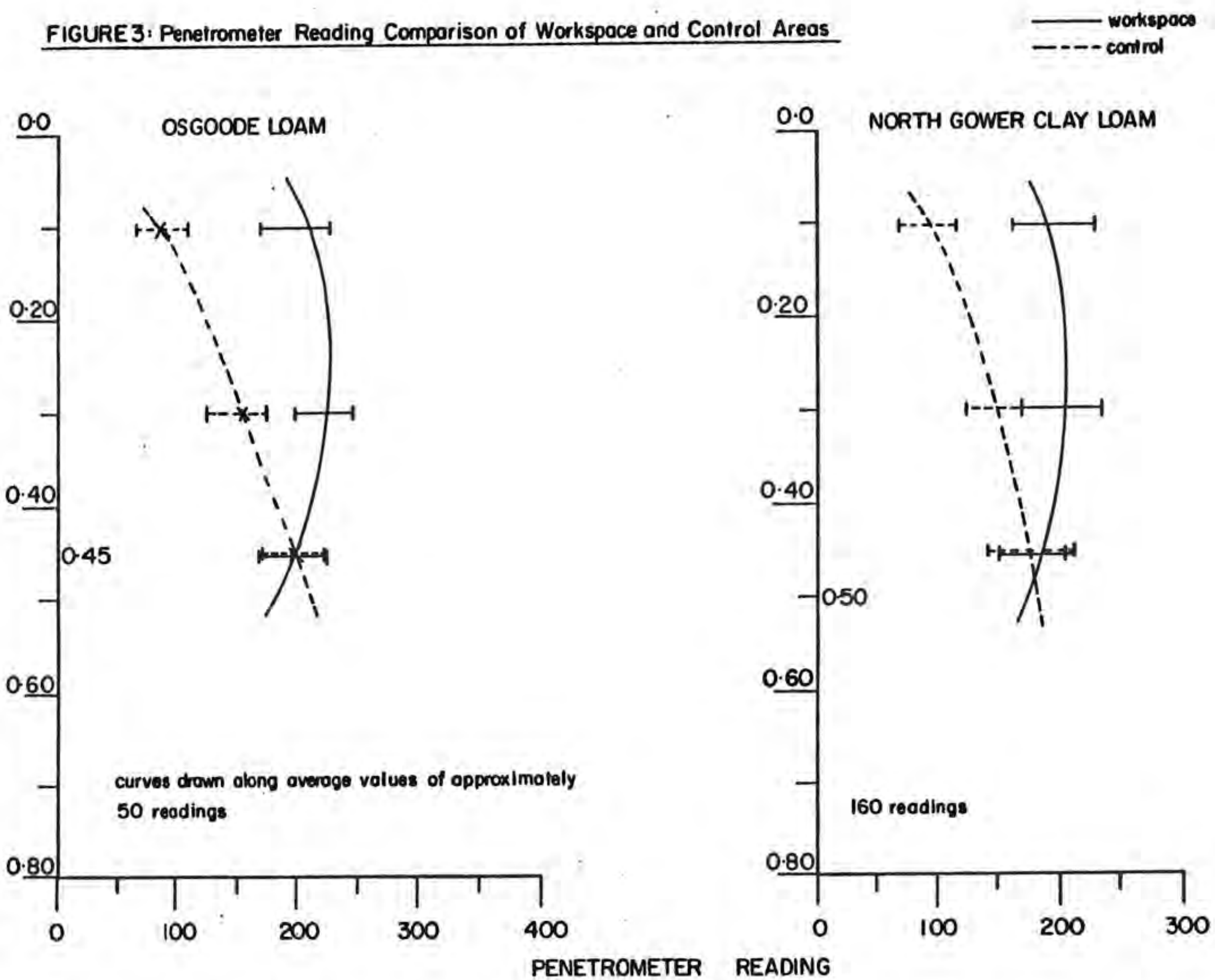


FIGURE 3: Penetrometer Reading Comparison of Workspace and Control Areas



by an undulating plain of stony, clay till, there was a legitimate concern that subsoiling would directly introduce stone into plough depth or dislodge it and allow it to migrate upward through frost action. It was feared that this would mean extra stone-picking and re-compaction of the soil, leading to a vicious clean-up cycle. Efforts were made to determine depth of the till layer by examining the trench walls and trench spoil and by selectively test-pitting prior to clean-up. Nevertheless, the specification for subsoiling depth had to remain flexible so that stony patches could be avoided; in fact, subsoiling depth was frequently reduced by field decision from 60 cm to 45 cm for this reason. Even so, considerable stone-picking was necessary in some cases.

A second concern related to subsoiling was the possible inversion of the soil profile and consequent topsoil/subsoil mixing. While the equipment used is designed to minimize this problem, dry subsoil is necessary for its proper action to be achieved. Where wet, plastic clay subsoil was encountered, a sliver of subsoil sometimes slid up the shank, to be deposited on the surface. While mixing from this source was relatively unimportant, subsoiling depth was reduced in parts of some fields to help control it.

Another source of mixing was encountered where soil was greatly compacted at the surface as well as at depth. The strength of the compacted layers caused them to slide up the shanks in a sheet before cracking into clods. In tumbling to the surface, the soil clods tended to become inverted. This problem was largely corrected by making two passes with the subsoiler, the first to a depth of 25 or 30 cm, the second to the recommended depth. Other implements, with straight shanks and lifting wings or shallower leading shanks might have had the same effect with only one pass.

The third concern about subsoiling is that it can only be done properly if the subsoil is dry enough to shatter and if the topsoil is dry enough for a tractor to maintain traction while handling the extra load. Weather and soils stayed sufficiently dry for both years of the North Bay Shortcut work, but there was a measure of luck involved; in most places in eastern Canada there are more unsuitable days for subsoiling each growing season than suitable. The extra working depth possible with the equipment selected by our contractor allowed subsoiling to be placed at the end of the clean-up sequence, even where topsoil had been removed over the working side of the right-of-way. Thus, there was flexibility to reschedule subsoiling for favorable weather conditions, if necessary, without delaying other clean-up operations. Moreover, there were essentially no compaction causing operations to be carried out after subsoiling.

Preliminary Results

In all, 85 properties were systematically probed with penetrometers and/or sampled for bulk density at two or three depths on and off the right-of-way. Of these, 77 were subsoiled, mostly to a depth of 45 cm. The total distance subsoiled was about 42 km and the production was roughly 3 km (4.8 ha) per day.

While TransCanada and its consultants are still in the process of evaluating the first-year results, a number of general observations are possible at this time. First, probing has demonstrated a reduction in resistance to penetration relative to control sites in adjacent fields (Table 4). Bulk density measurements indicate that this reduction should be beneficial to crop performance (TransCanada 1983b). Second, airborne colour infra-red data collected in June through cooperation of the Ontario Centre for Remote Sensing suggest no obvious, compaction-related infiltration or internal drainage problems on any of the subsoiled

TABLE 4: Depth of Compaction (maximum penetration of core sampler) in Summer 1983

Location +	Average depth of penetration *	
Off right-of-way	32	a
Spoil Stockpile	43	b
Trench	48	c
Workspace	41	b
Off right-of-way	33	a

\+ samples taken in transects of 5 points across right-of-way

* average over 37 properties sampled; means followed by same letter are not significantly different at the 1% level, by Duncan's New Multiple Range Test

properties. This observation is confirmed by a thorough ground-based survey which found only isolated cases of ponded water, usually calling for minor corrections of tile drainage repairs, micro-topography or previously undetectable seepage. In addition, an overview inspection of crop performance in early July showed normal crops over subsoiled properties. These preliminary observations are now being followed up with aerial colour infra-red crop data and quantified by means of soil sampling and sampling of mature crops. It should be recognized, though, that further monitoring (perhaps through a complete rotation) might be necessary to verify success. For best results, subsoiling should probably be followed by seeding down to a deep-rooted legume crop. Many farmers find this inconvenient, however, and return their fields to corn or grain production immediately following construction. Hopefully, this will not result in re-compaction and formation of a "plough-pan" on the right-of-way.

Conclusion

It should be clear from the foregoing discussion that subsoiling is potentially a very useful mitigative measure which can successfully be integrated into the pipeline construction and clean-up sequence. It should be equally obvious, however, that "DOING IT RIGHT" requires proper equipment, suitable soil conditions, skilled operators, on-going inspection and frequent field adjustments. A considerable amount of research remains to be done before subsoiling can be considered a standard or universal technique for inclusion in regulatory guidelines.

Regulators will always press industry for more detailed and precise specifications and for more objective criteria on which to base their regulations. To a degree, this is useful because it causes all concerned to study problems more carefully, to develop more information on which to base decisions and to place more information on the public record for the benefit of others. But to the extent that reliance on objective criteria reduces flexibility, and to the extent that it prevents qualified, experienced practitioners from making considered, professional judgements, it should be avoided.

References

Hare, M.O., W.R. Milne and W.H. Watt. 1984. North Bay Shortcut pipeline route selection process. Facility Siting and Routing, Energy and Environment Symposium. Banff, Alberta.

Moncrieff, I., E.E. Mackintosh, L. DeVries, and M. Hoffman. 1983. Rehabilitation of agricultural lands, Dawn-Kerwood loop pipeline. Proc. 8th Annual Meeting Canadian Land Reclamation Assessment, University of Waterloo, Waterloo, Ontario.

Shields, J.A. 1979. Possible impacts of pipeline construction on farmlands. Canadian Land Resource Institute, Ottawa. Technical Report. 14 p.

TransCanada PipeLines Limited. 1980. North Bay Shortcut environmental considerations, proposed North Bay to Morrisburg route. D.H. Duncan and Company Limited, Mission, British Columbia.

TransCanada PipeLines Limited. 1982. As-built environmental report, Morrisburg loop, 1981 and 1982 construction. D.H. Duncan and Company Limited, Mission, British Columbia.

TransCanada PipeLines Limited. 1983a. North Bay Shortcut environmental as-built report.
Volume 1 - As-built and summary environmental report. TransCanada PipeLines Limited.
Volume 2 - As-built report, Spreads 1 and 2. Northland Engineering Limited.
Volume 3 - As-built report, Spread 3. D.H. Duncan and Company Limited.
Volume 4 - As-built report, Major river crossings. I.E.C./Beak Consultants Ltd.

TransCanada PipeLines Limited. 1983b. North Bay Shortcut environmental as-built report addenda.
Volume 1 - Summary of addenda to environmental as-built reports. TransCanada PipeLines Limited (Ecological Services for Planning, Ltd., I.E.C./Beak Consultants Ltd.)
Volume 2 - Clean-up addendum, Spreads 1 and 2. Northland Engineering Limited.
Volume 3 - Clean-up addendum, Spread 3, D.H. Duncan and Company Limited.

EFFECTS OF TIME AND GRAZING REGIME ON REVEGETATION OF NATIVE RANGE AFTER PIPELINE CONSTRUCTION

by

M.A. Naeth and A.W. Bailey

Department of Plant Science

University of Alberta

ABSTRACT

Successful revegetation after pipeline construction in native rangeland requires an effective range management program to expedite a self-sustaining, erosion reducing ground cover.

The study area was located 50 km northeast of Brooks, Alberta. Two early season grazed sites and two late season grazed sites were selected in a pipeline corridor containing pipelines that were installed 3, 12, 16, 21 and 27 years ago.

Even after 26 years, species composition and ground cover over the rights-of-way were significantly different from the undisturbed areas. Grazing regime had a profound effect on all vegetative characteristics evaluated.

INTRODUCTION

Activities associated with transport of Alberta's petroleum resources necessitate pipeline construction. In 1981, there were 180,208 km of pipelines in the province of Alberta (Webb 1982).

Installation of a pipeline disrupts both the soil and the hydrology of an area as well as the flora and fauna associated with it. Each ecosystem reacts differently, thereby varying environmental impacts of pipeline installation and complicating quantification of cause and effect links between pipeline disturbances and such impacts.

Suitable pipeline installation techniques and reclamation procedures for a given ecosystem can be determined only if both the short and long term effects of pipeline construction are understood. Data demonstrating the mechanisms causing these effects have not been adequately documented. Most investigations in agricultural areas have concentrated on arable crop production, but provide inadequate information on ecosystem reconstruction and stabilization in natural uncultivated grasslands.

Optimum productivity on Solonetzic native range will only be attained if pipeline installation and revegetation procedures are based on firm knowledge of and are compatible with that ecosystem's functioning. The need to document and assess the impact of pipeline disturbances on Solonetzic native range ecosystems formed the basis for this study. It had two overall objectives:

1. To document and assess selected ecosystem responses to pipeline installation in native Mixed Prairie rangeland on Solonetzic soils in Southern Alberta.
2. To study the longevity of these selected ecosystem responses.

This presentation deals with two specific objectives:

1. To examine the effects of early and late season grazing on revegetation of pipeline disturbances.
2. To examine the above effects within different zones of construction activity and on different aged pipeline rights-of-way.

METHODOLOGY

Four study sites were located within a natural gas pipeline corridor approximately 10 km east of Princess, Alberta. Sites 1 and 4 were located in NE 15-20-11-4 and NE 16-20-11-4 respectively; and sites 2 and 3 in NW and NE 15-20-11-4 respectively. All four study sites were located within a 4 km distance. Studies were confined to the rights-of-way leased by NOVA, An Alberta Corporation, and to control areas immediately adjacent to the right-of-way (r-o-w). These control areas were utilized for extensively managed beef cattle production by the Eastern Irrigation District (EID).

Each of the four study sites was 100 m by 135 m, spanning five r-o-w with an undisturbed (control) area on either side. These sites were divided into 17 east-west transects representing different areas of pipeline construction activity and different ages of pipelines. Pipelines ranged in diameter from 86 to 107 cm and were installed in 1957, 1963, 1968, 1972 and 1981. Transects included the undisturbed prairie on either side of the pipeline r-o-w, the area directly above each trench, and the work, pipelay and stockpile areas. The area corresponding to the work, pipelay and stockpile transects of the older r-o-w was referred to as the between trenches transects.

The study sites had slopes of less than 2%. Soils were Solodized Solonetz or Brown Solod with prominent blowout patches. Vegetation was of the *Bouteloua-Stipa* (Blue grama-Spear grass) facies of the *Stipa-Bouteloua-Agropyron* (Spear grass-Blue grama-Wheatgrass) faciation. The 1981, 1972 and 1968 r-o-w were seeded to similar mixtures of introduced species including: *Agropyron cristatum, Elymus junceus, Agropyron riparium, Agropyron trachycaulum, Agropyron elongatum, Agropyron trichophorum, Elymus angustus, Medicago* species, *Onobrychis vicaefolia* and *Astragalus cicer* (crested wheatgrass, Russian wildrye, streambank wheatgrass, slender wheatgrass, tall wheatgrass, pubescent wheatgrass, Altai wildrye, alfalfa, sainfoin and cicer milk-vetch). The 1957 and 1963 r-o-w were not seeded. Sites 2 and 3 were in an early season grazed section of the range (grazed from May through July) and sites 1 and 4 were in a late season grazed section (grazed from August through November).

In 1982, transects were subdivided into four subtransects each 25 m in length and spanning the width of the transect. Twelve m^2 quadrats were randomly established in each transect. In 1983, individual transects were divided into 1 m by 1 m subtransects. At each site one hundred 0.10 m^2 (20 cm x 50 cm) quadrats were read in each transect.

In each quadrat ocular estimates of basal area were determined for individual species total live vegetation, total dead vegetation, and bare ground. Frequencies of each species in a quadrat were recorded.

Plant densities over the 1981 r-o-w were determined to quantify the establishment of introduced species and invasion by native species. In each site, four seeded rows were randomly selected in each of the following transects: 1981 trench, pipelay, work and stockpile. Twenty-five 1.0 m segments were randomly selected along each seeded row, and the number of introduced and native plants were counted in each row segment.

Chi square was used to test departure from expected values and to determine the homogeneity of two species with respect to frequency and cover.

RESULTS

The ground cover of the undisturbed prairie consisted of approximately 50% live vegetation, 30% dead vegetation (litter) and 20% bare ground. ***Selaginella densa*** (little club moss) was the dominant species, often comprising over 50% of the live vegetation. Dominant grasses included ***Bouteloua gracilis, Koeleria cristata*** and ***Stipa*** species (predominantly ***Stipa comata*** with small amounts of ***Stipa spartea*** var. ***curtiseta***). Together these three grasses represented up to 12% of the total ground cover, occurring with a mean frequency of 64%. Forbs were abundant, predominantly ***Artemisia frigida*** (a half-shrub), ***Opuntia polyacantha, Phlox hoodii*** and ***Sphaeralcea coccinea*** (pasture sage, prickly-pear cactus, moss phlox and scarlet mallow). Over 99% of the species were native.

Season of grazing had a substantial effect on vegetative composition. With early season grazing there was a decrease in live vegetation and an increase in litter and bare ground. In general, late season grazing resulted in increased basal area of many grasses and forbs.

With pipeline disturbance, botanical composition and ground cover changed significantly. The trenching disturbance was the most destructive compared to the grading and stockpiling operations of the other r-o-w transects.

Immediately following pipeline construction, vegetation declined to nearly 0.0% of the ground cover over the trench transect (Figure 1), and near 5% over the other disturbed transects. Species in all transects of the 1981 r-o-w had very low covers and frequencies. Over 95% of the species present had mean basal areas of less than 1% and approximately 60% had frequencies of less than 10%.

During the first year, vegetative cover over the trench had increased to approximately 5% of the ground cover (Figure 2). The 1972 trench had approximately 10% vegetative cover and approximately 90% bare ground. Over time vegetative cover increased on disturbed areas. Vegetative cover of the 1957, 1963 and 1968 r-o-w was approximately 40%. This compares with 20% bare ground from the undisturbed native rangeland.

Other disturbed transects of the 1981 r-o-w had less bare ground than did the trench transect in some sites. The work and stockpile transects in both years of the study often had nearly twice as much vegetative ground cover as the trench area did. The pipelay transect tended to have values between the trench and the other disturbed transects. The between trenches transect near the 1972 r-o-w had more vegetation than did the 1972 trench. Areas between the 1957, 1963 and 1968 trenches had basal areas similar to those of the adjacent trenches.

Over time the effect of grazing had a compounding effect with that of the pipeline disturbance. Older r-o-w under late season grazing tended to have less bare ground and more live vegetation and litter than did early season grazed sites (Figure 2).

Late season grazed sites had approximately four times as many native species over the 1981 r-o-w as did early season grazed sites. Although introduced species numbers were higher in late season grazed sites as well, the variability was high making the differences non-significant.

The effect of grazing regime on revegetation is most obvious when comparing the frequency and basal area of *Agropyron cristatum* (crested wheatgrass) and *Descurainia sophia* (flixweed). *Agropyron cristatum* dominated the 1968 and 1972 r-o-w under a late season grazing regime (Figure 3), but was only a minor component of the vegetative composition under early season grazing. No other introduced species had persisted and native species invasion had been accomplished only by a few ruderals. *Agropyron cristatum* was a dominant species under both grazing regimes immediately after a disturbance but within a year, frequency and basal area were decreasing under early season grazing.

Similar data were collected for *Descurainia sophia*. In 1982 *Descurainia sophia* dominated the 1981 r-o-w under a late season grazing regime, but under early season grazing the species was a relatively minor component of the vegetation (Figure 4). Similar patterns were observed for *Koeleria cristata. Bouteloua gracilis* and *Hordeum jubatum* (wild barley) tended to increase significantly under an early season grazing regime.

Few introduced species were present on the 1957 r-o-w, but large numbers of native species, particularly forbs, were present with both high covers and frequencies. The 1963, 1968 and 1972 r-o-w were similar in native species composition to that of the 1957 r-o-w. However, the number of introduced species dramatically increased in these trench areas.

In all sites, species composition of the 1957 r-o-w was not significantly different from that of the undisturbed transects. The 1981 trench transect was most similar to the 1981 pipelay transect. Under an early season grazing regime, the 1963, 1968 and 1972 r-o-w were more similar in botanical composition to the 1957 r-o-w than to the 1981 r-o-w or the undisturbed prairie. Under a late season grazing regime, these transects were significantly different from all other transects.

DISCUSSION

The trench area had more introduced species and generally had more species with lower basal area and frequency compared to those of the other transects. These other transects were not trenched, but only graded, and therefore more hospitable for regrowth from species with their roots still intact, or partially buried. This was particularly true for the forbs.

The higher basal area and frequency for many species and the large number of native species under late season grazing reflect the susceptibility of some species to early season grazing.

The majority of the species present are cool season forms. They begin growth in late March or early April, are heading or flowering in June, and have completed seed maturation by July. By August, most vegetation will be dormant or cured. These cool season species will be most affected by early season grazing. Severe defoliation during early stages of phenological development is often detrimental to seed production and even to the survival of some species, whose only means of reproduction is through seed. Species that can reproduce vegetatively are also stunted after severe defoliation because energy must be put into rebuilding photosynthetic parts and carbohydrate reserves necessary for winter survival.

Early maturing species that are late season grazed have a distinct advantage for survival over those that are grazed early in the season. By July and August, most early maturing species are entering summer dormancy and thus are usually more resistant to grazing. Some species, such as those of the *Stipa* genus, have very prickly seeds which are unpalatable to cattle. Species such as *Agropyron cristatum* are also coarse and unpalatable. Many of the forbs are declining in vigour, maturing seeds, or have already cured by the time late season grazing begins. Thus only later maturing species and those that experience autumn regrowth will be sensitive to grazing at this time. Grazing in late autumn will detrimentally affect these species which have not built sufficient carbohydrate reserves for winter survival, and those reproducing from seed, whose seed matures late in the season. With late season grazing, the native species on the work and stockpile areas could partially recuperate from the disturbance. Species in the early season grazed sites would be defoliated and trampled at a time when they were most vulnerable because of their low energy reserves. Thus many weedy species if early season grazed would not survive whereas those that were late season grazed would have time to recover from the pipeline disturbance before being subjected to the pressures of grazing. The trench area was the most severely disturbed, and would likely take longer to recover. Plant roots and Native seeds were not on the trench and only introduced seeds were present. These seeds are often planted late in the season and would not likely germinate as readily as the plants that were already present on the other transects would recuperate, thus accounting for the smaller number of plants over the trench transect.

Descurainia sophia is palatable in early spring but unpalatable by summer. *Koeleria cristata* (June grass) is a vigorous native invader as its prominence in the disturbed transects indicates. *Koeleria* reseeds bared areas readily, and because it begins growing early in the spring, can take advantage of the early spring moisture reserves (Coupland 1950).

The 1968 and 1972 r-o-w were seeded to a mixture containing *Agropyron cristatum* during the final stages of pipeline construction. *Agropyron cristatum* generally does not suffer frost damage nor winter kills and is highly drought resistant due to its extensive root system. It is also an excellent weed competitor. These characteristics make *Agropyron cristatum* a species well suited to eventual dominance of a disturbed area. Studies involving *Agropyron cristatum* on Mixed Prairie indicated that when *Agropyron cristatum* was grazed early in the spring native dominants expanded and competed successfully (Hubbard 1949).

The 1981 disturbance transects were dominated by introduced and native invaders, or weedy species. The older pipeline disturbances had many more native species, with loss of dominance by the introduced species. With time, the disturbed areas appear to be approaching the vegetative character of the undisturbed transects, but even after 26 years, there are still significant differences in botanical composition.

The large number of forbs present indicate the efficiency of these species in secondary succession. Forbs are generally more efficient than grasses in using environmental resources, such as wind, for the dissemination of seeds, and soil moisture and nutrients for germination and growth.

Data such as those presented in Figure 1 can be somewhat misrepresentative. If the basal area of *Selaginella densa* is taken into consideration, then the undisturbed live vegetation provided by other species is similar to those for older disturbed transects. Since *Selaginella densa* is unpalatable, the productivity of the area may not be dramatically reduced by pipeline disturbance, except over the 1981 r-o-w. Within 15 years the amount of live vegetation over the trenches has returned to near predisturbed conditions. Other transects of the r-o-w appear to approach these conditions within 10 years. Thus it appears that there is a fairly rapid return to predisturbed levels of palatable forage under the proper grazing regime. From a soil conservation point of view, this is not so. Although *Selaginella densa* is an unpalatable species, it does provide protection from erosion. The time required for *Selaginella densa* to invade these areas is not known. If many years are required, perhaps the protection against erosion would be provided by increased cover from the more palatable species that could increase in basal area under proper range management, making the presence of *Selaginella densa* unnecessary from a conservation view point and undesirable from a livestock grazier's point of view.

The r-o-w is attractive to the cattle because it often offers fresh palatable species. Cattle grazing the same range over a period of years tend to be attracted to the r-o-w each spring and often use it as a camping ground. Dugouts near the r-o-w also increase activity near the r-o-w long after the area has been grazed.

CONCLUSIONS AND RECOMMENDATIONS

Pipeline construction activities and subsequent operation of the line have a profound effect on the rangeland ecosystem. The most obvious effect is the reduction or removal of the vegetative cover over the r-o-w. The grazing regime imposed on the rangeland affects vegetative characteristics and thus affects reclamation efforts.

Although grazing slows revegetation progress, if properly managed it can be used to aid in weed control and enhance revegetative efforts without the detrimental economical implications that no grazing might have.

Based on the findings in this research the following recommendations are put forth:

Although fencing and weed control would be the most desirable way of establishing a ready ground cover, the high cost of this type of reclamation imposes more practical considerations.

The most economical alternative appears to be a properly managed grazing regime to return the land back to its inital use. It is important to know what the end land use will be and what grazing management is likely to be employed. Early season grazing eliminates or reduces weeds such as ***Descurainia sophia*** that readily colonize disturbed areas. It also reduces the dominating influence of ***Agropyron cristatum***. However, this grazing regime decreases vegetative cover and increases the amount of bare ground which has serious consequences in soil erosion. ***Agropyron cristatum*** has been considered a desirable species capable of increasing native range productivity. If so, then it must be grazed earlier in the season to ensure its palatability yet not grazed for so long at a high intensity that it is eliminated. Reducing both the stocking rate and the period of grazing for the first few years following revegetation would be beneficial. Rangeland should not be only autumn or spring grazed, but these regimes should be rotated periodically.

Dugouts must not be constructed near the r-o-w and other forms of passive control such as locating salt licks away from the r-o-w should be employed.

ACKNOWLEDGEMENTS

Funding by the Alberta Environmental Centre (AEC), Vegreville is gratefully acknowledged. NOVA, An Alberta Corporation and the Eastern Irrigation District (EID) are also acknowledged for access to their rights-of-way and adjacent undisturbed areas respectively.

Ms. B.M. Lardner provided valuable technical assistance during the study, particularly during the field season. Her efforts and interest in the project are gratefully acknowledged. Ms. W. Power is acknowledged for drafting of the figures.

REFERENCES

Coupland, R.T. 1950. Ecology of mixed prairie in Canada. Ecol. Monog. 20:272-315.

Hubbard, W.A. 1949. Results of studies of crested wheatgrass. Sci. Agr. 29:385-395.

Webb, C. 1982. The impacts of linear developments, resource extraction and industry on the agricultural land base. ECA. 82-17/IB25. Env. Council of Alta. Edmonton, Alta. 87 pp.

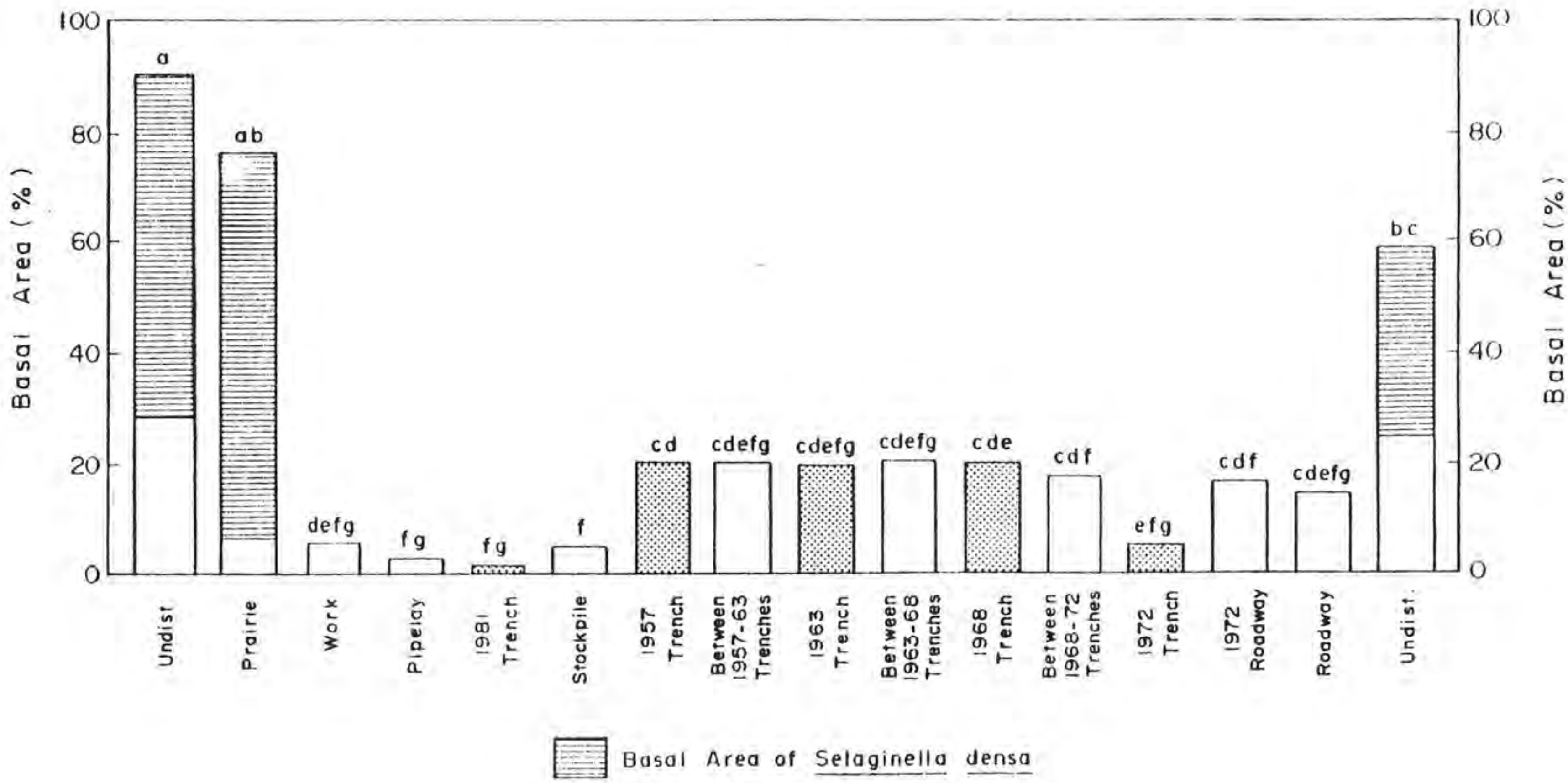


Figure 1. Mean percent live vegetation in June, 1982 (data are mean of three sites). Same letters denote no significant difference (Chi square test; $p<0.05$)).

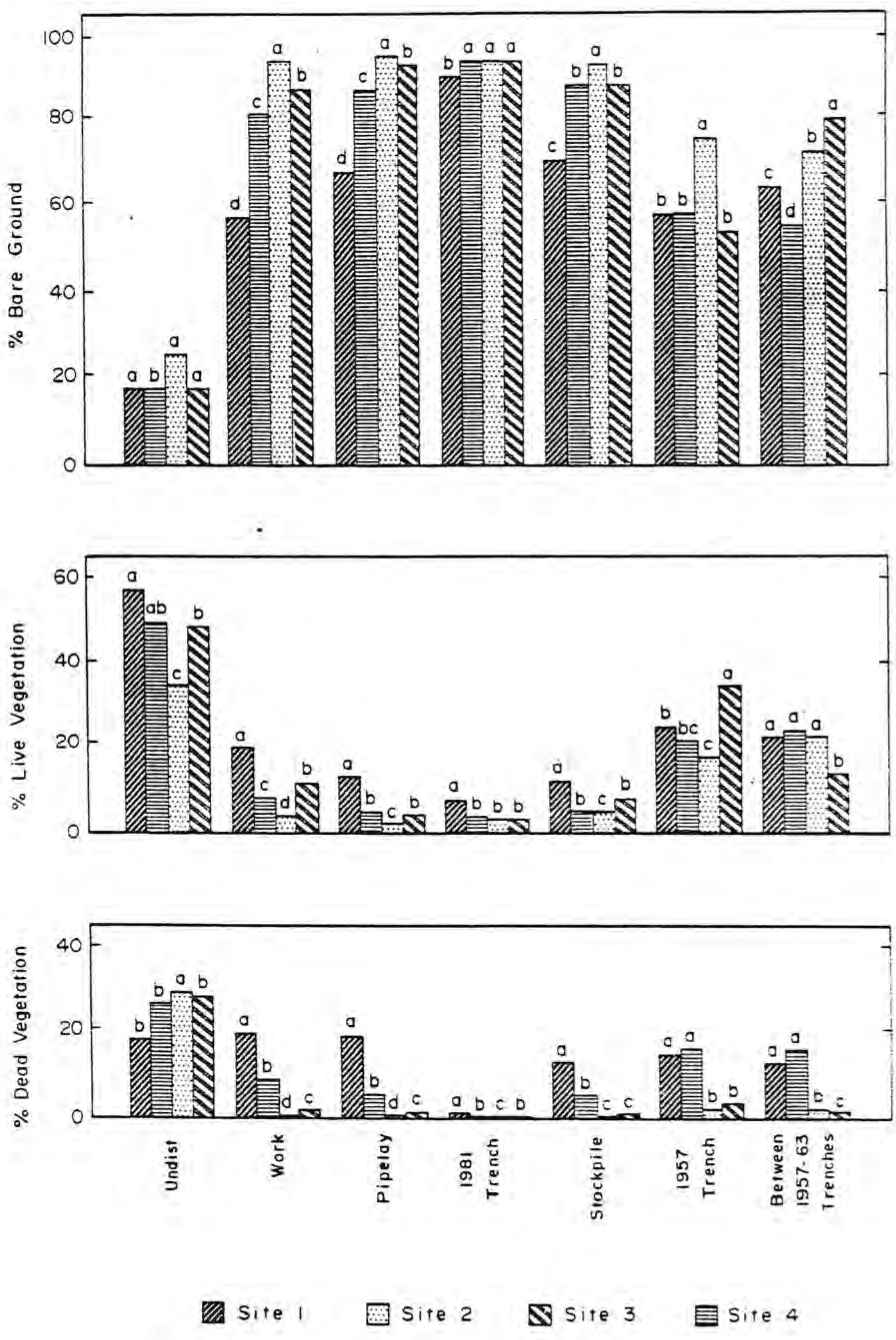


Figure 2. Mean percent ground cover in June, 1983. Same letters denote no significant difference (Chi square test; $p<0.05$).

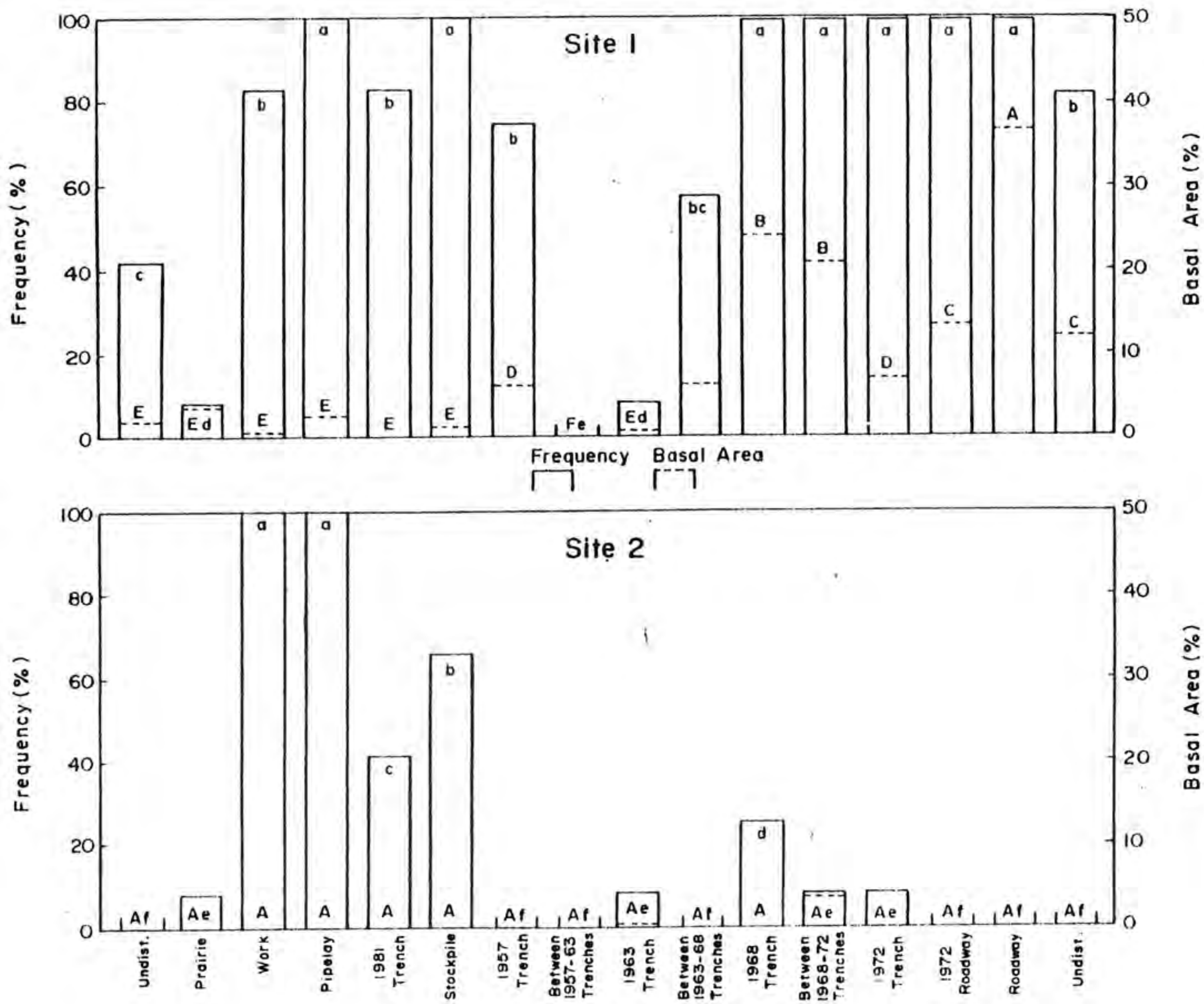


Figure 3. Mean frequency and basal area of *Agropyron cristatum* in June, 1982, in late season grazed (upper) a[illegible] [illegible]rly season grazed (lower) sites. Same letters denote no significa[illegible] [illegible]fference (Chi square test, $p<0.05$).

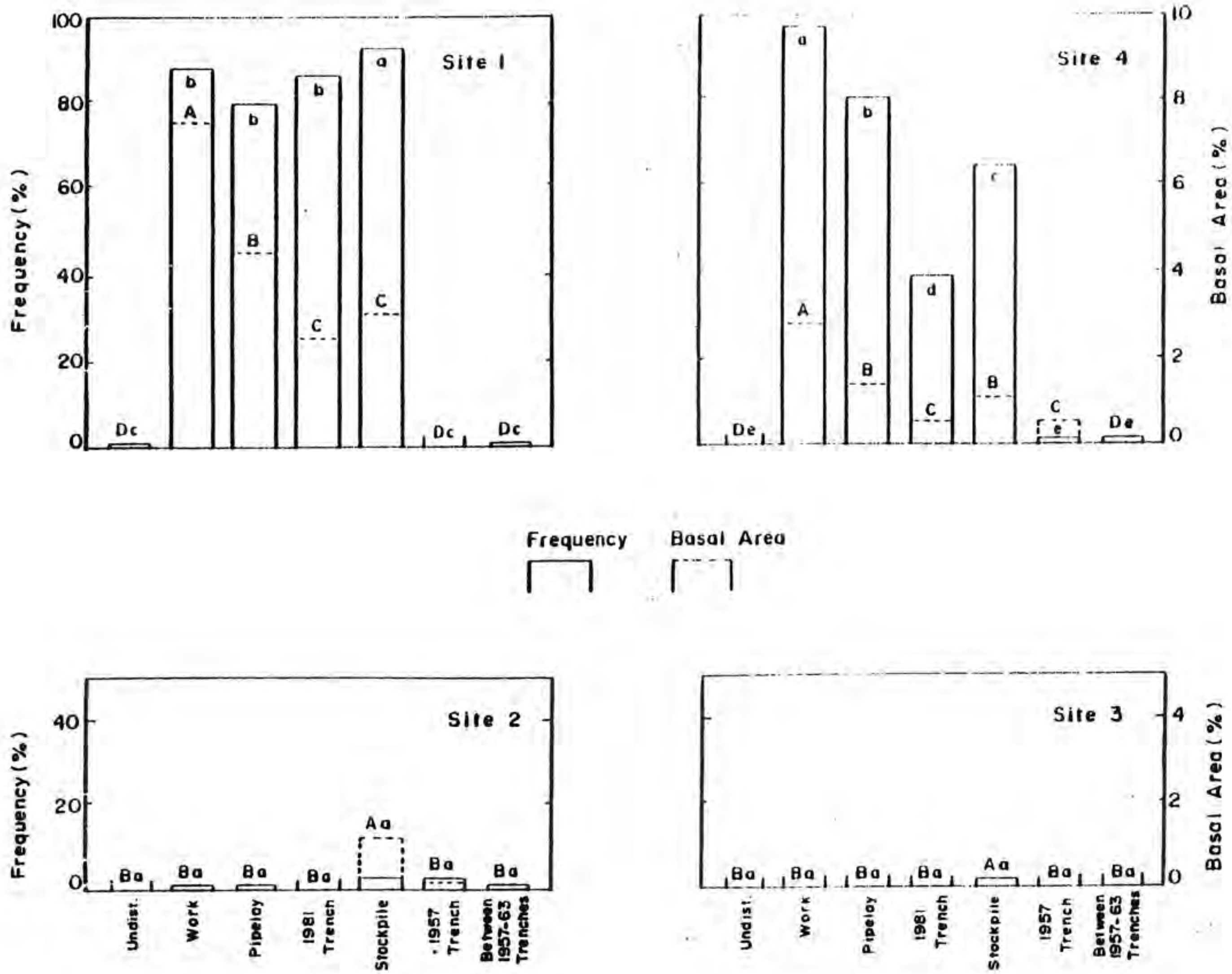


Figure 4. Mean frequency and basal area of *Descurainia sophia* on late season grazed (upper) and early season grazed (lower) sites in June, 1983. Same letters denote no significant difference (Chi square test; $p<0.05$).

REVEGETATION MONITORING OF THE ALASKA HIGHWAY GAS PIPELINE PREBUILD

Reinhard Hermesh*

Techman Engineers Ltd.

ABSTRACT

Vegetation monitoring of the Alaska Highway Gas Pipeline Southern B.C. Prebuild was undertaken in 1982 and again in 1983. The study was unique in that the same quadrats were re-examined in the second year. This permitted an evaluation of the year-to-year changes in vegetative cover on both the 2- to 3-year old Foothills Pipeline (FHPL) right-of-way and also on an adjacent 22-year old Alberta Gas Trunk Line (AGTL) right-of-way. The data suggests that considerable vegetative perturbations are occurring on both.

INTRODUCTION

In 1982 and again in 1983 the Northern Pipeline Agency let a contract to monitor the state of revegetation on the Foothills Pipe Lines (South B.C.) Ltd right-of-way (R.O.W.) following Phase I (Prebuild) construction

* Presently Head, Vegetation Group
Alberta Environmental Centre, Vegreville

in southern British Columbia. Monitoring of this revegetation is required by the Environmental Guidelines issued in 1980 under the Northern Pipeline Act (1978).

A major consideration when undertaking a monitoring program of this nature relates to the processes of plant succession. Odum in 1969 redefined what has become the classical concept of plant succession:

1. It is an orderly process of community development that is reasonably directional and therefore predictable.
2. It results from the modification of the physical environment by the community.
3. It culminates in a stabilized ecosystem.

In a reclamation monitoring program based on this classical concept we can theoretically determine the stage of the vegetative development and, knowing the time since abandonment, we can predict to some extent the rate and direction of community development. We can therefore determine whether plant succession is proceeding along a desired line and at a desired rate. If this is not the case we can suggest management practices which would manipulate the revegetation processes. However, can we make such deductions based on only one year's observation of the vegetative cover?

It should be noted that much of the data on which the concept of succession has been built comes from 'static-approach' studies which examined different vegetation types within similiar vegetation zones and then related them to hypothetical successional sequences (Maarel and Werger 1978). Recently, data is being obtained on the results of the vegetation changes monitored at one site over a period of many years. The results of some of these studies are now casting doubt upon the classical interpretation of successional processes (Connell and Slayter 1977, Glenn-Lewin 1980, Collins and Adams 1983, Peet and Christensen 1980, Beetink 1979). These authors suggest that succession may be individualistic in that plant community development is site specific and a relatively unpredictable stochastic process. Successional sequences in this model relate to factors such as the initial seed densities in the soil (Moore and Wein 1977, Egler 1954, Archibold 1980), the plant populations existing in the vicinity (Glenn-Lewin 1980) and the vegetative and seed dynamics of the initial species to become established (Peet and Christensen 1980).

The implications of the individualistic theory on a revegetation monitoring program are that:

- A one-time survey of the plant cover can not be used to establish the place in a successional sequence which would lead to a climax vegetation.
- There is no apriori reason why a disturbed site would reach a climax cover similiar to that in the surrounding area and the final cover may in fact remain quite different.
- Certain vegetation types such as shrub or grass cover within a forested region need not necessarily be unstable or transitional.
- Elements influencing plant community such as site and initial seed populations can be controlled or manipulated.

Since site condition and seed content are factors that greatly influence the type of vegetative cover in the establishing community, the manipulation of these factors can be used to influence the development of the desired type of cover. For example, the type and quantity of seeds present as well as the soil conditions will influence cover development. If the quantity of agronomic seed on a pipeline is very high, native species may be excluded and a strictly agronomic grass-legume cover formed. This may be desirable or undesirable depending upon the requirements.

STUDY OBJECTIVES

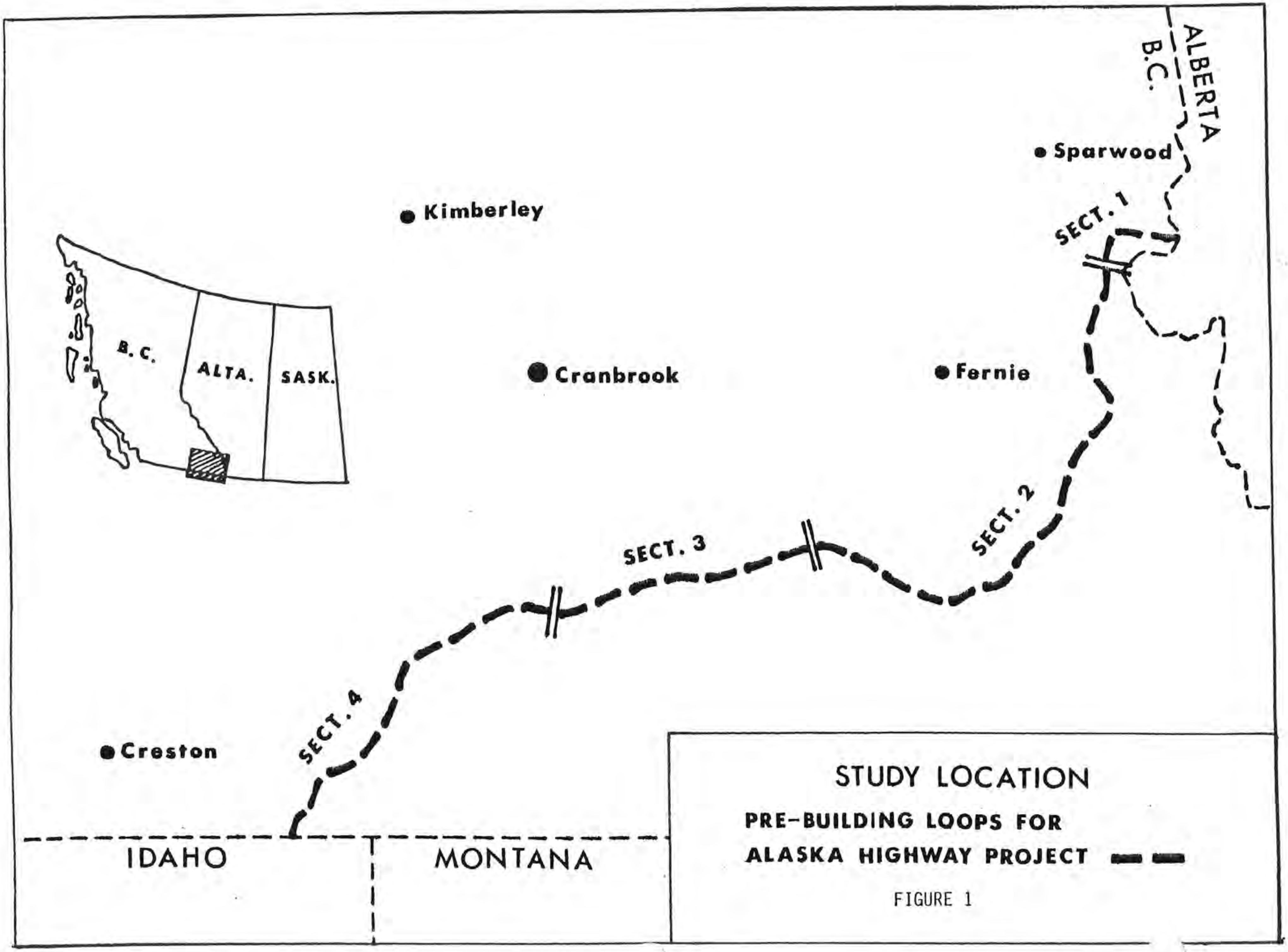
Objectives of this study were:

- To assess the establishment success of seeded agronomic species.
- To compare the year-to-year variation in vegetative cover on two right-of-ways of different ages.

LOCATION

The study area is located in the East Kootenay Mountains and the adjoining lowlands of southern British Columbia. The area is divided into four sections which comprise Phase I looping of the existing 36-inch (914 mm) pipeline of Alberta Natural Gas Company Ltd built in 1961. Very little new R.O.W. required clearing of vegetation. Distances and elevation of the four sections studied are shown in Figure 1 and listed in Table 1.

Regional climate is largely determined by local topographic and wind conditions. Along the pipeline R.O.W. climatic zones range from semi-arid



STUDY LOCATION

PRE-BUILDING LOOPS FOR ALASKA HIGHWAY PROJECT

FIGURE 1

to cool alpine. Despite these diverse climatic conditions, three biogeoclimatic zones can be identified along the route (Table 1).

Table 1

ELEVATION (METRES A.S.L.) OF PIPELINE SECTIONS MONITORED

Section	Length (km)	Elevation Range (m)	Biogeoclimatic Zones
1	4.6	1341-1615	Engelmann Spruce/Subalpine Fir
2	33.4	1212-2134	Engelmann Spruce/Subalpine Fir
3	24.5	762-1381	Interior Douglas Fir
4	26.7	800-1052	Interior Western Hemlock

CONSTRUCTION AND RECLAMATION

Construction of the South British Columbia Phase I sections began in mid-August 1980, when permission to proceed with clearing on Section 2 was granted, and was completed by late winter. The cleanup and revegation program was carried out in late summer of 1982. The revegetation sequence was by Sections in numerical order. Topsoil was salvaged at only on lands designated as agricultural. On non-agricultural lands compacted soil was loosened by dragging a heavy harrow over the graded surface with a skidder. This procedure was not always effective on hard packed or baked surfaces.

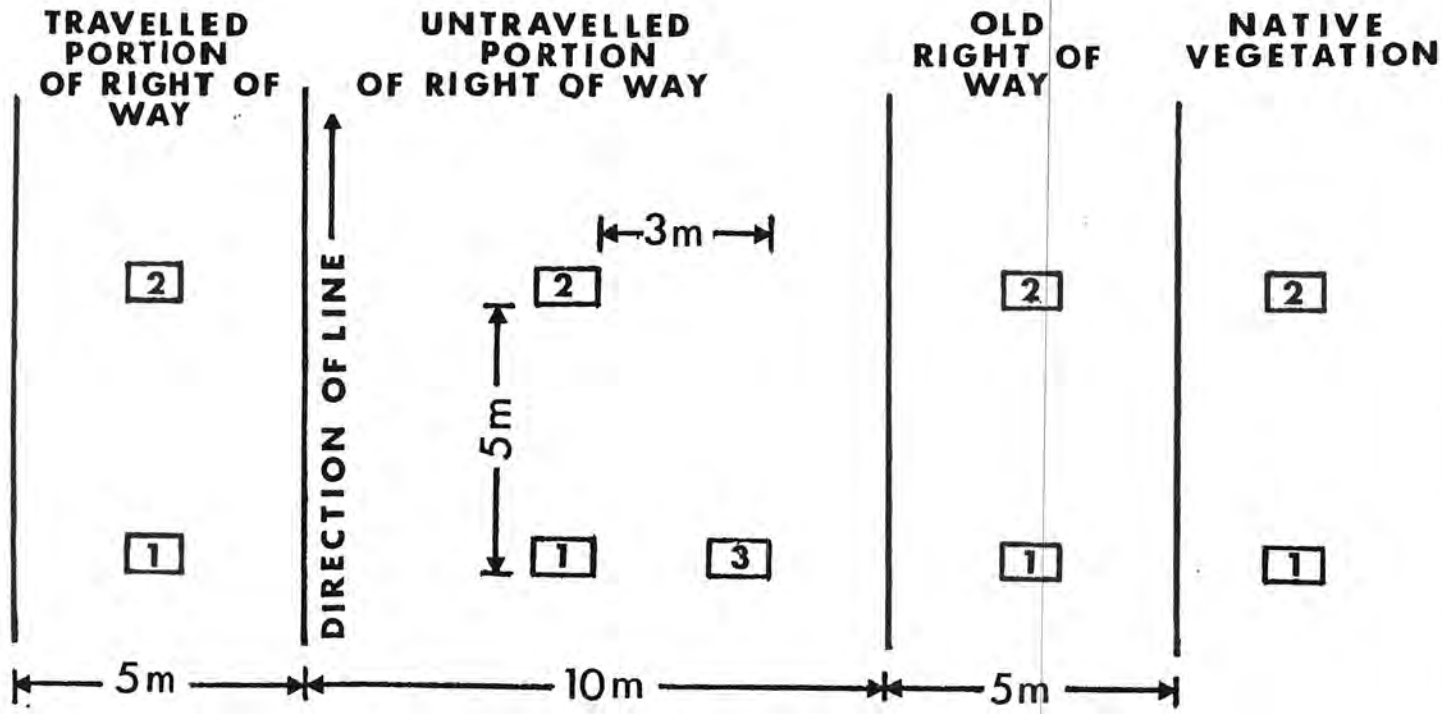
Seed and fertilizer were broadcasted by two John Deere 1840 4-wheel-drive tractors equipped with front and back cyclone seeders. A chain harrow was then used to incorporate the seed and fertilizer into the soil.

In addition to this general procedure, hydroseeding and mulching of approximately 6 ha of terrain with a slope greater than 18 degrees was carried out on parts of Sections 2 and 4.

Seed mixes of agronomic grasses and legumes were applied at the rate of 20 kg/ha. Fertilizer (16-20-0) was applied at a rate of 300 kg/ha.

METHODOLOGY

In August 1982 a total of 82 vegetative monitoring sites were established in the 4 zones. Sites consisted of 3 one-half square metre permanently marked quadrats placed on both the 2-year old (FHPL) and on the adjacent 22-year old (AGTL) R.O.W. The bottom right and top left corner of each quadrat was permanently marked. The location of the first quadrat in each site was a point near the centre of the R.O.W. The corner pin of this initial quadrat was randomly located, the second quadrat was located 5 metres down the R.O.W. from the first. The third quadrat was 3 metres to the right of the initial marker. The sites within each sample zone were selected to cover the area of concern, thus on a hill, sites were placed at 3 to 5 slope positions depending upon the length of the slope, its steepness, and the extent of erosion.



LAYOUT OF A TYPICAL PLOT SITE

FIGURE 2

In 1982 and again in 1983 the species in each quadrat were recorded and the percentage cover in each quadrat estimated. A list also was made of all species found in the 10 m x 5 m area surrounding the nest of quadrats. A 35 mm slide photograph was made of each quadrat and of the general site. These slides are on file at the Northern Pipeline Agency. The plant nomenclature in this report largely follows that of Taylor and McBride (1977).

RESULTS

A comparison of the 1982 and 1983 plant covers on the untravelled 2-year old FHPL R.O.W. is presented in Table 2 and on the 22-year old AGTL R.O.W. in Table 3. On both R.O.W.'s the vegetation cover of the sites monitored on Sections 1 and 2 had significantly increased.

Section 3 was of some interest since the overall vegetation cover on the untravelled R.O.W. sites had increased 50% over 1982 even though, on four of the 17 sites the cover had decreased. At the same time on the 22-year old AGTL R.O.W. there was a significant decline (13.5%) in the cover from that of 1982.

The mean cover values of the plots on Section 4 nearly doubled from 1982 to 1983(Table 2). The highly significant increase from 32% to 61% cover suggests that plant establishment is being achieved at a rapid pace.

The mean increase in cover on all plots on the untravelled portions of the FHPL R.O.W. was 14.2% (Table 3). Such an increase would be expected of

Table 2

CHANGES IN VEGETATION COVER ON THE 2-YEAR OLD FHPL RIGHT-OF-WAY

Section		1982	1983	Change	Significance
1	Mean Cover	17.7%	29.5%	+11.8%	**
2	Mean Cover	8.1%	16.6%	+ 8.5%	**
3	Mean Cover	18.2%	27.9%	+ 9.7%	**
4	Mean Cover	31.8%	61.1%	+29.3%	**

** Significant at the 99% confidence level.

Table 3

CHANGES IN VEGETATION COVER ON THE 22-YEAR OLD
AGTL RIGHT-OF-WAY

Section		1982	1983	Change	Signficance
1 + 2	Mean Cover	72.8%	92.8%	+20.0%	**
3	Mean Cover	56.7%	43.2%	-13.5%	**
4	No old R.O.W. in this Section.				

** Significant at the 99% confidence level.

Table 4

DIFFERENCES BETWEEN 1982 AND 1983 VEGETATION COVERS

	FHPL R.O.W. 2 Years Old	AGTL R.O.W. 22 Years Old
Mean of Differences in Cover	14.7% ± 15.3	17.2% ± 10.0
Range of Changes in Cover	-5% to +63%	-34% to +23%
Mean Overall Change in Cover	+14.2%	-5.9%

a vegetation cover which is still in the establishment stage. However, over the same year the cover on the 22-year old R.O.W. showed a decline of 5.9% (Table 3). This decline occurred mainly on the lower elevation Section 3 of the line, an area which may have been suffering because of a very dry year.

In comparing the cover on the two R.O.W.'s it should be noted that there was no difference in the mean variation of the covers (14.7% vs 17.2%) or in the magnitude of the ranges of variation of covers (68% vs 53%). Only the overall direction of change (fluctuations from 0) is positive on the FHPL R.O.W. (+14.2%) and is negative on the 22-year old AGTL line (-5.9%) (Table 4).

It must be remembered in an overall comparison of sections that the sites are not randomly located within the sections but were located at critical, or potential problem areas. The overall figures for the vegetation covers therefore do not represent the more favorable conditions found along much of the R.O.W. They can be used to give more insight into what is happening along the 'worst case' portions of the route. Areas not monitored were frequently observed to have a much greater vegetation cover than the monitored portions.

DISCUSSION

The year-to-year changes in plant cover result from two factors, a stochastic one which operates on both the 2- and 22-year old R.O.W.'s and an establishment component operating mainly on the 2-year old R.O.W.. The latter represents the natural year-to-year increase as the cover becomes established.

Although the data from this study cannot be used to lend any weight to either the individualistic or classical theories of plant successsion, they do point out several factors:

1. The year-to-year variability in plant cover was large.
2. The amount of fluctuation in plant cover was not different on the 2- and 22-year old pipeline R.O.W.'s.
3. Variation in cover has a stochastic component and in the early years a plant establishment component.

The implications of the results for pipeline monitoring programs are:

1. A one-time evaluation of the R.O.W. is not sufficient to make definitive statements about the adequacy of long-term vegetation cover. This would be the case no matter which theory of plant succession is correct.
2. Permanently-installed quadrats are a good method of monitoring year-to-year vegetative changes as they permit objective evaluation of the vegetation dynamics along the R.O.W.
3. Comparison among R.O.W.'s of different ages and with adjacent vegetation are important in determining the overall vegetation dynamics of a reclaimed site.

ACKNOWLEDGEMENT

The courtesy of the Northern Pipeline Agency in allowing use of material from their 1982 and 1983 reports entitled "Revegetative Success Monitoring Alaska Highway Gas Pipeline (Phase 1) Southern British Columbia" is greatly appreciated.

Literature Cited

Archibold, O.W. 1980. Seed input is a factor in the regeneration of strip mine wastes in Saskatchewan. Can J. Bot. 58:1490-1495.

Atmospheric Environment Service "Canadian Normals". Downsview, Ontario. Volumes 1-S1, 2Si, 1975.

Beeftink, W.G. 1979. Vegetation dynamics in retrospect and prospect. Introduction to the proceedings of the second symposium of the working group on succession research on permanent plots. Vegetatio 40:102-105.

Collins, S.L. and D.F. Adams. 1983. Succession in grasslands: thirty-two years of change in a central Oklahoma tallgrass prairie. Vegetatio 51:181-190.

Egler, F.E. 1954. Vegetation Science Concepts I. Initial floristic composition, a factor in old field vegetation development. Vegetatio Acta. Geobotonica 4:412-417.

Glenn-Lewin, D.C. 1980. The individualistic nature of plant community development. Vegetatio 43:141-146.

Maarel, E. and M.J.A. Werger. 1978. On the treatment of succession data. Phytocoenosis 7:257-278.

Moore, J.M. and R.W. Wein. 1977. Viable seed populations by soil depth and potential site recolonization after disturbance. Can.J. Bot. 55:2408-2412.

Mueller-Dombois, D. and H.E. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons. Toronto.

Odum, E.P. 1969. The strategy of ecosystem development. Science 164:262-270.

Peet, R.K. and N.L. Christensen. 1980. Succession: Population process. Vegetatio 43:131-140.

Penfound, W.T. and E.L. Rice. 1957. Plant population changes in a native prairie plot plowed annually over a five year period. Ecology 38:148-150.

Slaney, F.F. and Company Ltd. and Bayrock Surficial Geolody Ltd. 1974. Environmental considerations proposed: Alberta natural gas pipeline system expansion, Vancouver, November, 1974.

Taylor, R.L. and B. MacBride. 1977. Vascular plants of British Columbia: A descriptive resource inventory. University of British columbia Botanical Garden Technical Bulletin No. 4.

POST-MINING GROUNDWATER CHEMISTRY AND THE EFFECTS OF IN-PIT COAL ASH DISPOSAL: PREDICTIVE GEOCHEMICAL MODELING BASED ON LABORATORY LEACHING EXPERIMENTS

by

M.R. Trudell, D. Cheel, S.R. Moran [1]

ABSTRACT

Laboratory leaching tests including 10:1 and 40:1 water to sediment ratios and saturated-paste extracts, have been used to determine the salt yielding properties of overburden materials as well as coal ash. This salt yield data, expressed as soluble salt in the appropriate water to solids ratio for field conditions, can be used to predict the salinity and composition of spoil groundwater, and the effects of coal ash disposal on spoil groundwater chemistry. The concentration of ionic species at varying sediment to water ratios is computed using the aqueous geochemical model PHREEQE, which allows consideration of mineral solubility constraints (particularly calcite, dolomite and gypsum), various partial pressures of carbon dioxide, and ion exchange.

The predictive model has been tested at three mine sites in central Alberta, with ash disposal considered at two sites. There is good agreement between the predicted and observed spoil groundwater chemistry at Diplomat Mine (mainly glacial drift overburden), Vesta Mine (mixed Horseshoe Canyon Formation bedrock and drift overburden) and Highvale Mine (mixed Paskapoo Formation bedrock and drift overburden). Disposal of coal ash in mine pits at Diplomat and Vesta Mines is predicted to increase the total dissolved solids in the spoil groundwater to 10,300 mg/l above a background of 5000 mg/l at Diplomat Mine and to 10,500 mg/l above a background of 6500 mg/l at Vesta Mine. The predicted groundwater composition and salinity for ash in spoil at Vesta Mine is in excellent agreement with the composition and TDS of 10,383 mg/l observed in a well installed in an ash site at Vesta Mine.

---

[1] Alberta Research Council, Terrain Sciences Department, Edmonton, Alberta

INTRODUCTION

The surface mining of coal has a significant impact on the quality of groundwater in and adjacent to mined areas. In almost all cases groundwater in reclaimed areas is more saline than the pre-mining groundwater, and is of different composition (Trudell and Faught, in prep.; Van Voast, 1982; Williams et al., 1983). In order to make planning decisions, particularly in terms of groundwater resource potential and long-term soil salinization in reclaimed areas, it is desireable to predict post-mining groundwater chemistry based on parameters from the pre-mining setting.

METHODOLOGY

The model for predicting post-mining groundwater chemistry presented in this paper has three components: (1) Quantification of soluble salts in overburden materials by laboratory leaching experiments; (2) Production of hypothetical 'spoil' material based on overburden characteristics; (3) Consideration of geochemical processes within resaturated 'spoil' material by means of the aqueous geochemical model PHREEQE (Parkhurst et al., 1980).

Overburden Characterization

The soluble salt producing characteristics of overburden materials were determined by two types of leaching tests; a 10:1 (water:sediment) extract, and a saturated paste extract. For each type of test, the cumulative frequency distribution of electrical conductance (EC) in the extract was used as the basis for characterizing the salinity of overburden materials. Small groups of samples corresponding to various EC percentiles were selected to represent the observed range of overburden salinity. The average salt yield, expressed in grams of salt per kg of sample was determined for each EC percentile group. This analytical treatment was carried out separately for glacial drift overburden and bedrock overburden, which have been identified as the two principal geochemical units that make up mine spoil (Trudell et al., 1983).

Hypothetical 'Spoil'

Hypothetical 'spoil' is made by combining the salt yield characteristics of drift and bedrock on the basis of the average relative thickness of drift and bedrock in the vicinity of a mine site. In producing this spoil, the porosity is assumed to be 30%, and the density of solid particles 2.65 g/cm^3. Upon saturation with water all of the pore space will be occupied with water, and therefore, 1 L of water will be in contact with 6.2 kg of solid spoil material. Consequently, the soluble salt from 6.2 kg of hypothetical spoil will be available to dissolve in 1 L of water.

Aqueous Geochemical Model

The dissolution of salts in spoil groundwater is subject to the constraints of mineral solubility (mainly calcite, dolomite and gypsum), partial pressure of carbon dioxide (P_{CO_2}, higher than atmospheric) as well as ion exchange. The salts from 6.2 kg of 'spoil' are dissolved (numerically) in 1 L of water, using the aqueous geochemical model PHREEQE to account for these processes. Any soluble salt in excess of the solubility limit of the minerals calcite, dolomite and gypsum is precipitated and the amount precipitated is determined. The partial pressure of CO_2 is fixed at a level characteristic of reclaimed spoil, which has been reported as typically .02 to .06 atm (Wallick, 1983). Ion exchange, primarily Ca^{2+} – Na^+, is approximated based on a modified selectivity coefficient (K') as defined by Parkhurst et al., (1980) where

$$K' = \frac{[Na^+]^2}{[Ca^{2+}]} ,$$

the square brackets indicating thermodynamic activity. This approximation is reasonable under conditions in which the reservoir of ions on the exchanger is very large (and therefore approximately constant) relative to the amount of exchanging ions in the solution. K' values were determined for drift and bedrock overburden on the basis of calcium and sodium activities in groundwater samples from unmined sites. To represent the range of observed K' values in overburden materials a log mean K' value was determined, plus a 'minimum' K' (log mean -2 standard deviations) and a 'maximum' K' (log mean +2 standard deviations) were determined. The ion exchange characteristics of the spoil were then approximated by thickness-weighted average K' values, for each pair (drift and bedrock) of minimum, mean and maximum K' values.

RESULTS

Spoil groundwater chemistry predicted using the geochemical model has been compared with observed groundwater chemistry in reclaimed spoil at three mine sites in central Alberta (Figure 1): Vesta and Diplomat Mines in the Battle River Mining Area (200 km southeast of Edmonton) and Highvale Mine in the Lake Wabamun Mining Area (100 km west of Edmonton). In addition, a predicted range of spoil groundwater chemistry was determined for Paint-earth Mine, in the Battle River area.

Vesta Mine

At Vesta Mine the overburden consists of calcareous clay till (drift) and fine-grained near-shore, clastic sedimentary rock of the lower Horseshoe Canyon Formation (Late Cretaceous) in average relative proportions of 0.3733 drift: 0.6267 bedrock. The salt yielding characteristics of the overburden materials are summarized in Table 1, and the parameters used in conducting the modeling are listed in Table 2.

The predicted spoil groundwater chemistry from various EC percentile groups is shown in Figure 2 and summarized in Table 3, compared with the observed spoil groundwater chemistry at Vesta Mine. Of predictions developed from the 10:1 dilution data, an acceptable match was obtained mainly for sample groups corresponding to the 0.1 and 0.5 EC percentiles. Mean and maximum K' values were used in obtaining a match with the observed spoil groundwater chemistry. The predicted total dissolved solids (TDS) concentrations from three samples of this group ranged from 7100 to 7700 mg/L, which corresponds well to the mean TDS of 7443 mg/L observed in the spoil groundwater. Two other 10:1 dilution samples fell in the TDS range from 12700 mg/L to 15500 which compares well with the upper limit of observed spoil groundwater salinity (maximum TDS = 13800 mg/L). The predicted composition, like the predicted salinity, also corresponds well with the mean spoil groundwater composition as well as the high sulfate composition.

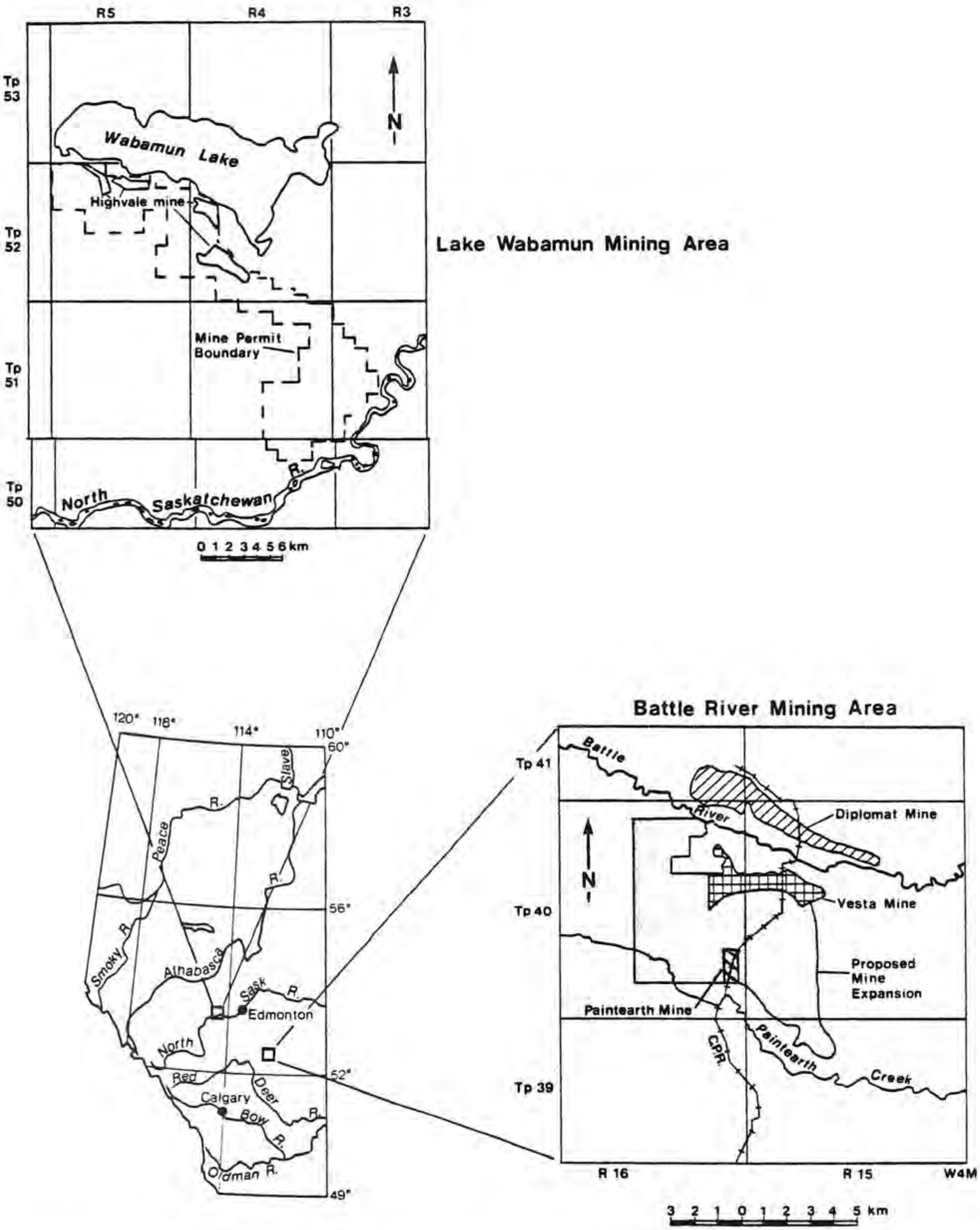


Figure 1. Location of study mines in the Battle River Mining Area and Lake Wabamun Mining Area, central Alberta

Table 1. Summary of Overburden Soluble Salt-Yielding Characteristics

Overburden Type	Method	EC Percentile	# Samples	Average Salt Yield (g/kg) Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4^{-2}	HCO_3^-	Cl^-	TDS
Battle River Area Overburden - Diplomat, Vesta and Paintearth Mines											
Drift	S.E.	.1	4	0.004	0.005	0.006	0.002	0.010	0.024	0.004	0.055
		.5	4	0.029	0.008	0.068	0.026	0.232	0.117	0.008	0.487
		.9	4	1.119	0.040	0.430	0.151	3.726	0.345	0.011	5.821
Bedrock	S.E.	.1	14	0.496	0.036	0.004	0.001	0.233	0.944	0.027	1.740
		.5	12	0.144	0.009	0.014	0.002	0.225	0.287	0.025	0.705
		.9	4	0.964	0.032	0.068	0.011	1.211	0.942	0.120	3.348
Drift	10:1	.1	2	0.295	0.047	0.069	0.052	0.585	0.661	0.027	1.736
		.5	4	1.390	0.163	0.157	0.089	2.953	0.585	0.029	5.366
		.7	5	1.394	0.140	0.274	0.368	3.492	0.569	0.027	6.264
		.9	2	1.570	0.063	0.762	0.561	7.200	0.381	0.019	10.556
Bedrock	10:1	.1	5	0.708	0.040	0.062	0.121	0.262	0.554	0.025	1.772
		.5	6	0.821	0.052	0.038	0.163	0.375	1.292	0.045	2.786
		.7	8	1.144	0.090	0.046	0.100	0.551	1.162	0.022	3.115
		.9	4	1.338	0.093	0.041	0.110	0.952	1.306	0.018	3.858
Highvale Mine Overburden											
Drift	S.E.	.5	4	0.302	0.013	0.010	0.002	0.244	0.540	0.006	1.117
		.7	4	0.111	0.009	0.032	0.007	0.064	0.333	0.016	0.572
		.9	4	0.197	0.008	0.020	0.004	0.743	0.311	0.021	1.304
Bedrock	S.E.	.5	6	0.194	0.018	0.011	0.003	0.095	0.439	0.020	0.780
		.7	6	0.183	0.005	0.003	0.008	0.015	0.292	0.044	0.550
		.9	4	0.230	0.008	0.005	0.002	0.087	0.476	0.037	0.845
Drift	10:1	.1	4	0.248	0.089	0.080	0.017	0.276	0.496	0.059	1.265
		.5	5	0.637	0.084	0.047	0.012	0.595	0.803	0.060	2.238
		.7	3	0.773	0.054	0.031	0.016	0.769	0.763	0.038	2.444
		.9	3	0.652	0.054	0.609	0.161	4.163	0.768	0.136	6.543
Bedrock	10:1	.1	3	0.354	0.049	0.041	0.005	0.197	0.813	0.038	1.497
		.5	3	0.542	0.044	0.034	0.004	0.289	1.208	0.042	2.163
		.7	4	0.695	0.053	0.031	0.002	0.221	1.322	0.057	2.381
		.9	3	0.685	0.075	0.034	0.003	0.171	1.136	0.071	2.175

Note: S. E. = saturation extract
10:1 = 10:1 Dilution test

Table 2. Summary of parameters used in the geochemical model for the prediction of post-mining groundwater chemistry.

Mine	Relative Thickness Drift	: Bedrock	P_{CO2} (atm)	Ion Exchange (K') min	mean	max
Diplomat	1.000	: 0.000	0.14	3.006×10^{-3} -	0.151 0.036	7.621 (Ca-Na) 0.832 (Mg-Na)
Vesta	0.3733	: 0.6267	0.04	0.424	1.148	8.433
Paintearth	0.000	: 1.000	0.03	-	3.837	8.954
Highvale	0.2381	: 0.7619	0.02	2.928×10^{-3}	0.3042	31.412

Note: '-' indicates value not used

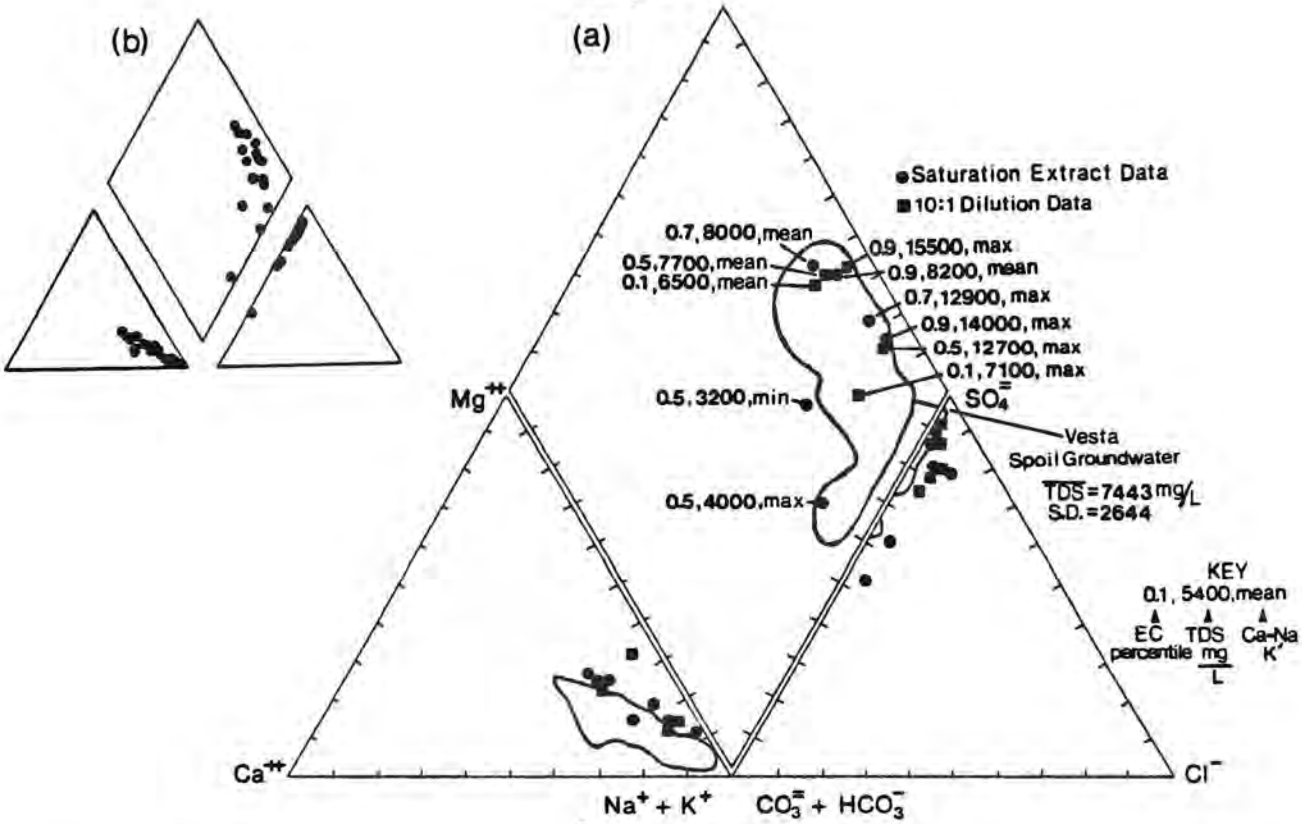


Figure 2. (a) Piper trilinear diagram of calculated spoil groundwater chemistry at Vesta Mine
(b) Observed composition of spoil groundwater samples from Vesta Mine

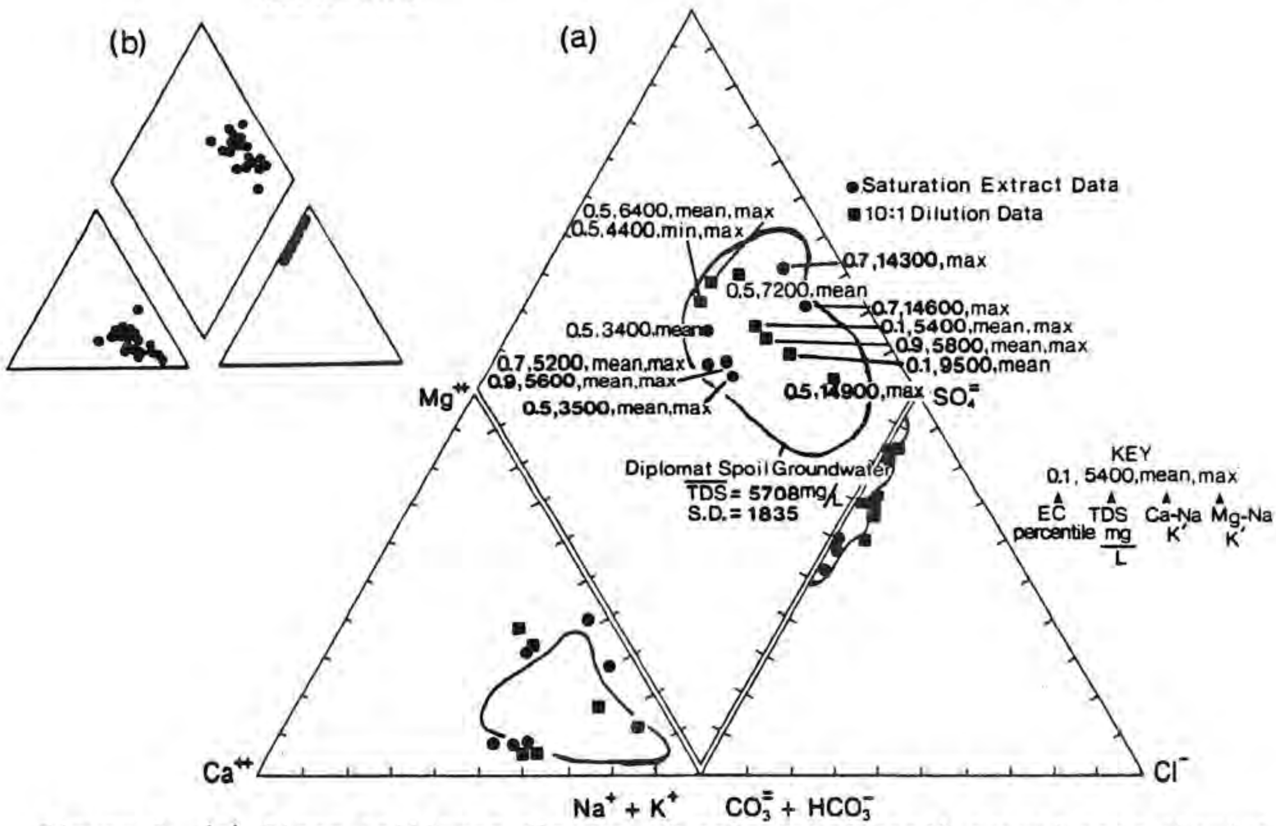


Figure 3. (a) Piper trilinear diagram of calculated spoil groundwater chemistry at Diplomat Mine. Single value for K' refers to Ca-Na K'; two values refer to Ca-Na, Mg-Na K', respectively. (b) Observed composition of spoil groundwater samples from Diplomat Mine

Groundwater chemistry predictions for Vesta Mine spoil based on saturation extract data tend to bracket the observed spoil groundwater composition and salinity. An acceptable match is obtained with sample groups corresponding to the 0.5, 0.7 and 0.9 EC percentiles, and predicted salinities include a lower range (3200 to 4000 mg/L TDS) and upper range (8000 to 14000 mg/L TDS) that correspond to the minimum (4500 mg/L) and maximum (13800 mg/L) observed spoil groundwater TDS concentrations, respectively. Similarly, the predicted composition includes the low-sulfate and high-sulfate range of observed composition. As with the 10:1 dilution, mean and maximum K' values were associated with the best-fit predictions.

TABLE 3

COMPARISON BETWEEN PREDICTED AND ACTUAL SPOIL GROUNDWATER COMPOSITIONS

MINE	PREDICTED RANGE TDS (mg/L)	PREDICTED MEAN TDS (mg/L)	ACTUAL RANGE TDS (mg/L)	ACTUAL MEAN TDS (mg/L)
Diplomat	3,400 - 14,600	5,840	2,038 - 12,766	5,708
Vesta	3,200 - 15,500	7,425	4,508 - 13,805	7,443
Paintearth	4,000 - 9,800	7,400	----	---
Highvale	2,000 - 6,900	4,740	1,219 - 6,855	3,668

Diplomat Mine

At Diplomat Mine the overburden is almost entirely made up of calcareous clay till that is typical of the Battle River mining area. Consequently, only the salt yielding characteristics of the drift leach-test samples were considered for the prediction of spoil groundwater chemistry at Diplomat Mine. The overburden salt-yield characteristics for Diplomat Mine are summarized in Table 1, and the parameters used for the geochemical model are listed in Table 2.

Predictions of groundwater chemistry based on 10:1 dilution data match the observed mean composition of spoil groundwater at Diplomat Mine, and as at Vesta Mine include the mean to upper range of observed salinity (Table 3 and Figure 3). The 0.1 and 0.5 percentile groups of the 10:1 dilution samples best match the observed concentrations, and predicted TDS values of 5400 to 6400 mg/L and 9500 to 14900 mg/L correspond to actual mean (5708 mg/L) and maximum (12766 mg/L) TDS concentrations, respectively, in groundwater at Diplomat Mine. Because of the relatively large amount of soluble magnesium in the leach test extracts of drift materials, in several cases it was necessary to consider Mg^{2+} – Na^{+} exchange in addition to Ca^{2+} – Na^{+} exchange to best match the observed composition and salinity. The procedure for considering Mg^{2+} – Na^{+} exchange was identical to that used for Ca^{2+} – Na^{+} exchange, i.e. based on K' values determined from unmined drift groundwater samples. Mean and maximum Ca^{2+} – Na^{+} K' values, together with maximum values of K' for Mg^{2+} – Na^{+} exchange, were used in arriving at the predicted groundwater chemistry.

The pattern of predicted spoil groundwater chemistry based on saturation extract data is essentially the same at Diplomat Mine as was found at Vesta Mine; that is, the predicted values bracket the observed composition and salinity as illustrated in Figure 3, and saturation extract sample groups corresponding to 0.5, 0.7 and 0.9 EC percentiles match the upper and lower range of sulfate composition in the observed groundwater composition. Also, the predicted salinity ranges, from 3400 mg/L to 5600 mg/L TDS and from 14300 to 14600 mg/L TDS correspond reasonably well to the minimum (2000 mg/L) and maximum (12766) observed TDS concentrations. As with the 10:1 dilution, mean and maximum Ca^{2+} – Na^{+} K' values and maximum Mg^{2+} – Na^{+} K' values were used in the predicted groundwater chemistries.

Highvale Mine

The overburden at Highvale Mine in the Lake Wabamun mining area consists of glacial drift (silt, clay and till) and continental, clastic sedimentary rock of the Paskapoo Formation (Upper Cretaceous-Paleocene) in relative proportions of 0.2381 drift:0.7619 bedrock. The salt yielding properties of overburden materials at Highvale Mine are summarized in Table 1, and the parameters utilized in the geochemical model are listed in Table 2.

A comparison of predicted versus observed spoil groundwater chemistry is illustrated in Figure 4 and summarized in Table 3. As at the Battle River

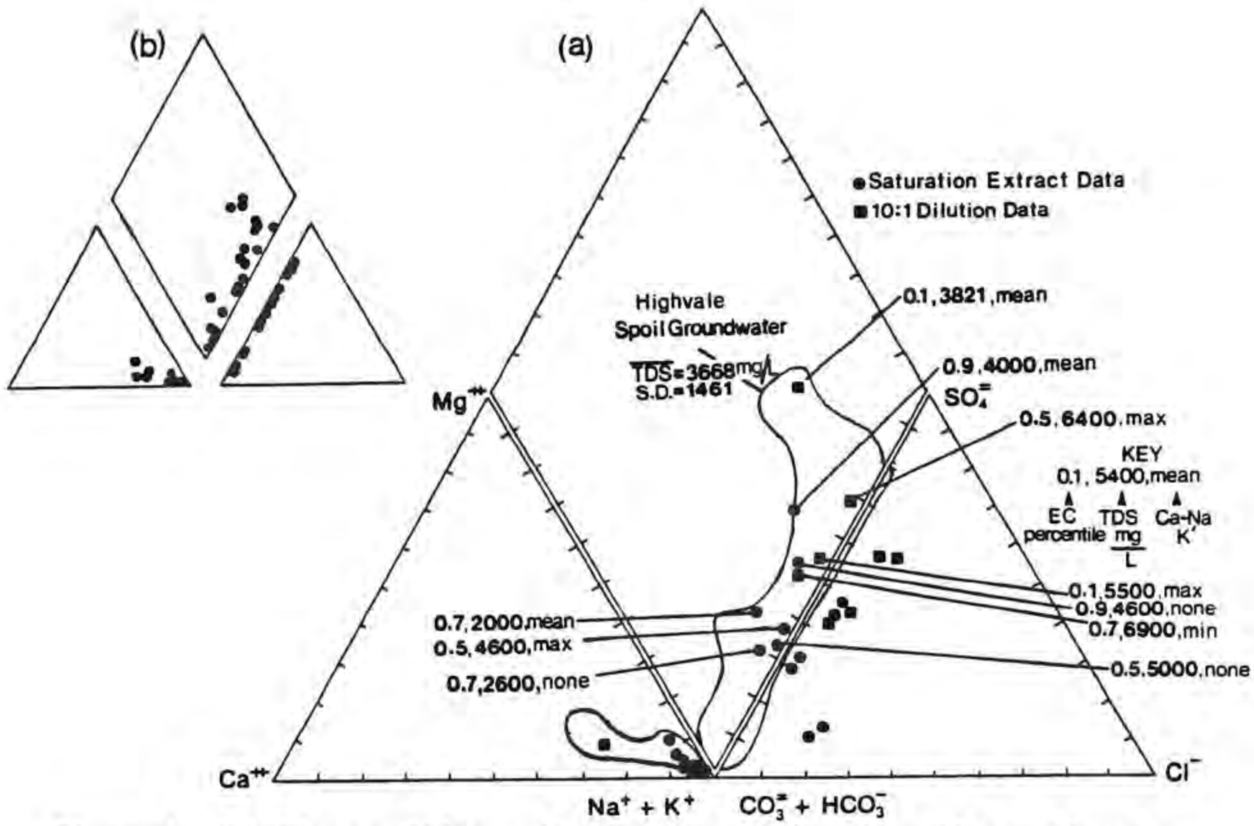


Figure 4. (a) Piper trilinear diagram of calculated spoil groundwater chemistry at Highvale Mine
(b) Observed composition of spoil groundwater samples from Highvale Mine

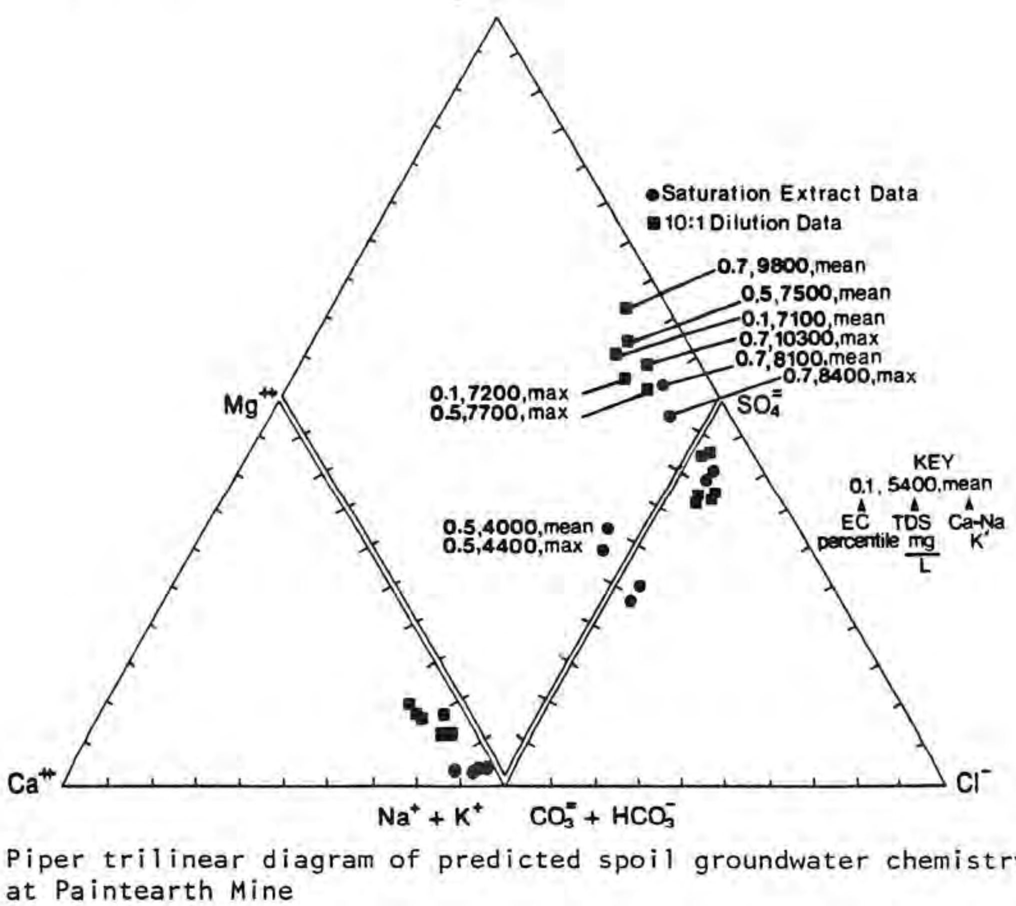


Figure 5. Piper trilinear diagram of predicted spoil groundwater chemistry at Paintearth Mine

mining area the ion exchange characteristics of the overburden materials were based on pre-mining groundwater samples, however, very little data from undisturbed sites are available close to the instrumented spoil area at Pit 01 of the mine. Consequently, the quantification of overburden ion exchange characteristics at this site may not be a reliable basis for estimating spoil ion exchange/properties.

The predicted groundwater chemistry at Highvale Mine differs from those at Battle River area mines in that saturation extract-based predictions correspond to the minimum and mean of observed chemistry (as opposed to minimum and maximum), and 10:1 dilution-based predictions correspond to the upper range of observed spoil groundwater chemistry. Predictions based on 10:1 dilution data groups from 0.1, 0.5 and 0.7 EC Percentiles, with maximum or minimum K' values, yielded groundwater TDS concentrations of 5500 to 6950 mg/L, compared to the observed salinity of spoil groundwater which has a mean TDS concentration of 3668 mg/L, a standard deviation of 1461, and a maximum of 6855 mg/L. The salinity predicted from saturation extract data ranges from 2000 mg/L to 5000 mg/L, and is in reasonable agreement with the minimum (1220 mg/L) to mean (3668 mg/L) observed TDS concentrations, as well as the observed spoil groundwater composition. The data groups corresponding to 0.5, 0.7, and 0.9 EC percentiles again provided the best match, and mean and maximum K' values, or no consideration at all of ion exchange, provided the best match for the observed spoil groundwater chemistry. The agreement obtained without considering ion exchange may reflect (1) low ion exchange capacities of the overburden materials, or (2) poor representation of local ion exchange properties from regional overburden data. Further investigation of the role of ion exchange as a predictive parameter is required to resolve this apparent inconsistency.

Paintearth Mine

Paintearth Mine in the Battle River mining area was opened in late 1981. In the area first mined the glacial drift cover was very thin (on the order of 30 cm) and salvaged as subsoil. Consequently, the spoil at Paintearth Mine is made up almost entirely of bedrock from the Horseshoe Canyon Formation.

The predicted groundwater chemistry for spoil at Paintearth Mine is illustrated in Figure 5 and summarized in Table 3. Since wells in the spoil at Paintearth Mine are still dry, the predicted groundwater chemistry is truly a prediction, an evaluation of which will be undertaken when the spoil resaturates. The essential feature of spoil groundwater at Paintearth Mine, based on the predictive model, are expected to be: TDS range from 4000 to 10000 mg/L; mean TDS approximately 7100 to 7500 mg/L; composition Na^+ - $SO_4^=$, with Ca^{2+} + Mg^+ comprising as much as 30% of the cation fraction, and HCO_3^- generally as much as 20% of the anion fraction.

Sulfate Reservoir

An important feature of the geochemical model is its ability to quantify the amount of undissolved sulfate remaining in the spoil after one pore-volume of flushing. This sulfate, probably in the form of gypsum, will be available for re-dissolution as fresh water recharges the spoil, thereby acting to maintain relatively high salinity groundwater in the spoil for an extended period of time.

The amount of undissolved sulfate in the spoil (the sulfate 'reservoir') for Diplomat and Vesta mines is summarized in Table 4. At Highvale Mine, all of the predicted water chemistry examples, from both 10:1 dilution and saturation extract data, showed no remaining sulfate. At Paintearth Mine, only one sample out of 10 indicated undissolved sulfate, and from that sample (10:1 dilution, EC 0.7 group, mean K' value) only 2.8% of the original sulfate remained undissolved.

Data from Diplomat and Vesta Mine, on the other hand, indicate that a significant amount of sulfate can remain undissolved. At Vesta Mine, as much as 76% of the original sulfate remained undissolved, with saturation extract and 10:1 dilution tests yielding comparable results. At Diplomat Mine, as much as 94 percent of the original sulfate remains in the solid phase, with the 10:1 dilution data better quantifying the total available sulfate and therefore probably providing a better estimate of the sulfate reservoir. This likely results from the solubility limits of gypsum reached during the saturation extract test, thereby underestimating the total soluble sulfate in the sample.

Table 4. Sulfate Reservoir in Spoil After One Pore-Volume Leaching

Mine	Method[1]	Sample Group EC Percentile	*K'	Moles/Kg $SO_4^=$ Reserve	%Original $SO_4^=$ Reserve
Vesta	SE	0.5	mean	0.	0
		0.5	max	0.	0
		0.7	mean	0.013	76
		0.7	max	0.008	46
		0.9	max	0.009	39
	10:1	0.1	mean	0.	0
		0.1	max	0.	0
		0.5	mean	0.009	63
		0.5	max	0.0035	25
		0.9	max	0.0194	57
Diplomat	SE	0.5	mean,max	0.	0
		0.7	mean	0.	0
		0.7	max,max	0.	0
		0.7	mean,max	0.011	82.5
		0.9	mean,max	0.035	90.4
	10:1	0.1	mean,max	0.0016	25.5
		0.5	min,max	0.029	93.7
		0.5	mean,max	0.028	89.8
		0.9	mean,max	0.070	93.7
Highvale	SE,10:1	all classes		0.	0

1 SE = saturation extract; 10:1 = 10:1 Dilution test

* single value refers to Ca-Na K°; two values are Ca-Na, Mg-Na K° values, respectively

From these results it is clear that the presence of high-salinity, calcareous till in spoil material can have a significant impact on the gypsum saturation characteristics of the spoil groundwater, and on the buildup of a sulfate reservoir in the spoil material. These results suggest that at Highvale and Paintearth Mines spoil groundwater salinity should decrease significantly after the first pore-volume of spoil resaturation, whereas at Diplomat and Vesta Mine the salinity of spoil groundwater will remain high during flushing by additional pore-volumes.

Effects of Coal Ash Disposal

The disposal of coal ash in pits at surface coal mines has the potential to significantly alter the chemistry of the spoil groundwater. To evaluate the magnitude of this alteration, the salt-yielding characteristics of fly ash and bottom ash from the Battle River Generating Station (Alberta Power Ltd.) in the Battle River mining area were determined from a 40:1 (water: sediment) leaching experiment. A procedure very similar to the one described above for predicting post-mining groundwater chemistry was used to evaluate the interaction between ash and spoil groundwater. The geochemical model PHREEQE was used to numerically dissolve the soluble constituents of fly ash and bottom ash in spoil groundwater. The modeling procedure was calibrated against two sets of laboratory experiments (one at atmospheric P_{CO_2}, the other at 0.25 atm P_{CO_2}), then used to predict the results of interaction of spoil groundwater and ash under in-pit disposal conditions.

The results of ash disposal on groundwater from Diplomat and Vesta Mines are illustrated in Figures 6 and 7. Significant increases in almost all species are expected, with increases in total dissolved solids from 690 to 4355 mg/L for bottom ash and fly ash respectively, at Vesta Mine, and from 1877 to 5408 mg/L for bottom ash and fly ash respectively, at Diplomat Mine. At both mines there is little change in spoil groundwater composition due to bottom ash disposal, but a significant increase in the percentage of sodium as a result of fly ash disposal, as illustrated in Figure 6.

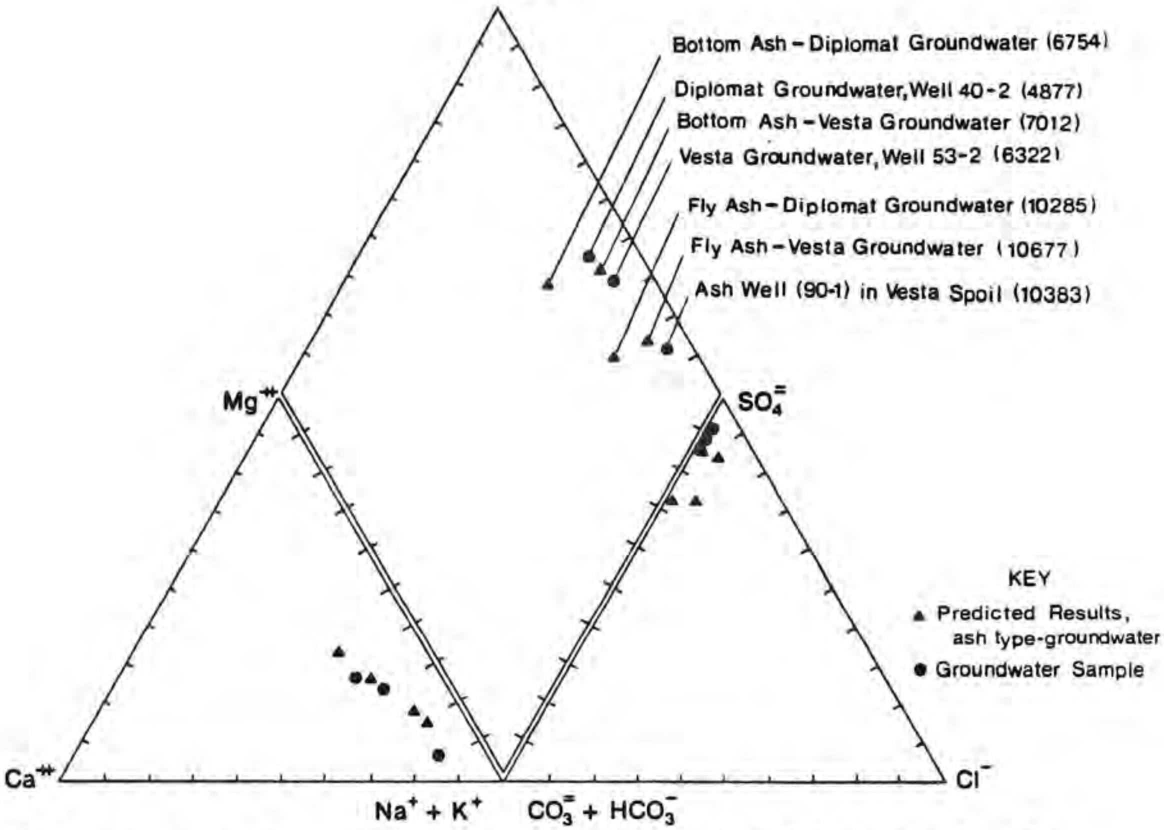


Figure 6. Piper trilinear diagram of geochemical modeling results for combinations of coal ash and spoil groundwater. Groundwater compositions are included for Vesta spoil groundwater, Diplomat spoil groundwater and well in an ash disposal area of Vesta Mine. Included in brackets are TDS values in mg/L.

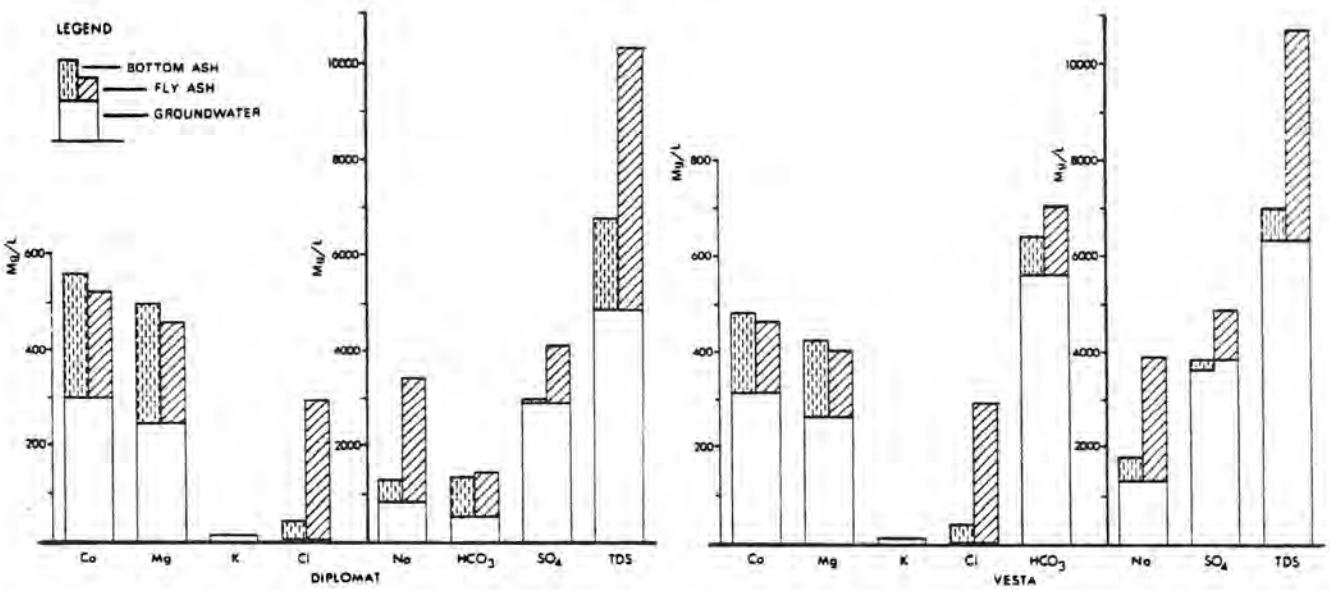


Figure 7. Graphical representation of the predicted effects of fly and bottom ash disposal on spoil groundwater chemistry at Diplomat and Vesta Mines.

A sample of groundwater has been collected from a well (90-1) in an ash disposal site at Vesta Mine. As shown in Figure 6, the predicted composition and salinity (10,677 m/L) based on Vesta spoil groundwater - fly ash in very good agreement with the actual composition and salinity of groundwater (10,383 mg/L) at the disposal site.

CONCLUSIONS

Pre-mining overburden characteristics can be used to successfully predict post-mining spoil groundwater chemistry. Leach test extracts, including both 10:1 dilution and saturated pastes are suitable for characterizing overburden salt-yielding characteristics, but in calcareous materials the 10:1 dilution provides a better estimate of total salt yield.

Overburden salt yielding characteristics used in conjunction with the geochemical model PHREEQE provide a reasonable estimate of the range of spoil groundwater composition and salinities that have been observed at several mine sites. Ion exchange, based on a modified selectivity coefficient determined from pre-mining groundwater samples, is an important process in most spoil groundwater settings, but further study is required to fully evaluate the role of ion exchange and to examine other techniques for quantifying this parameter.

For predicting post-mining groundwater chemistry, data groups corresponding to the 0.5 and 0.7 EC percentiles from saturation extract tests, and 0.1 and 0.5 EC percentiles from 10:1 dilution tests, provided the best match with observed spoil groundwater chemistry. Also, in most cases, mean and maximum K' values were used to provide good agreement with observed spoil groundwater chemistry.

In spoil where saline calcareous drift is a significant component, a large percentage of the available sulfate remains undissolved after one pore-volume of flushing, allowing for significant salinity to develop in subsequent pore-volumes of spoil groundwater.

ACKNOWLEDGEMENTS

This study was supported by the Alberta Heritage Savings Trust Fund and administered through the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation Reclamation and Council.

REFERENCES

Parkhurst, D.L., D.C. Thorstenson and L.N.P. Plummer. 1980. PHREEQE - a computer program for geochemical calculations. United States Geological Survey. Water Resources Investigations 80-96. NTIS Report No. USGS/WRD/WR1-80/018.

Trudell, M.R., A. Maslowski, E. Wallick, and S.R. Moran. 1983. Prediction of groundwater chemistry in reclaimed landscapes, In Fedkenheuer, A.W. (ed) Proceedings: Second Alberta Reclamation Conference, Edmonton, Alberta, February 1983. Alberta Chapter, Canadian Land Reclamation Association, Pub. #CLRA/AC 83-1, pp. 238-251.

Trudell, M.R. and R.L. Faught. In prep. Chemistry of Groundwater in Mine Spoil. Alberta Research Council, Plains Hydrology and Reclamation Project Report for submission to the Reclamation Research Technical Advisory Committee, Alberta Land Conservation and Reclamation Council.

Van Voast, W.A. 1982. An update on mine spoil hydrology, south-eastern Montana: pC-4-10 to C-4-15 in Munshower, F.F. and S.R. Fisher Jr., co-chairmen, Proceedings of a Symposium on Mining and Reclamation of Coal Mined Lands in the Northern Great Plains, Mar. 8-9, Billings, Montana. Montana Agricultural Expt. Station Research Paper No. 194.

Wallick, E.I. 1983. Gas composition in the unsaturated zone as an index of geochemical equilibrium in reclaimed landscapes. In Fedkenheuer, A.W. (ed) Proceedings: Second Alberta Reclamation Conference, February 1983, Edmonton, Alberta. Canadian Land Reclamation Association, Pub. #CLRA/AC 83-1, pp. 225-237.

Williams, T.T., R.L. Koob, and P.D. Rechard (ed.). 1983. Surface and groundwater problems associated with potential strip mine sites: U.S. Environmental Protection Agency, Extraction Technology Branch, Cincinatti, Ohio, Final Completion Report, Grant R-803727.

ASSESSMENT OF HORIZONTAL AND VERTICAL PERMEABILITIES FOR THE ROSEBUD-MCKAY INTERBURDEN ROSEBUD MINE, COLSTRIP, MONTANA

Peter M. Norbeck
Western Energy Company
Colstrip, Montana

Abstract

At the Rosebud Mine near Colstrip, Montana, the Rosebud Coal seam is mined but not the underlying McKay coal. Although existing data suggest no cause for concern, the possibiility that post mine spoils water could move downward through 3 to 30m of interburden and degrade Mckay water quality has had to be addressed. The question of vertical flow was addressed by means of permeameter tests on core samples of the interburden as well as aquifer test data from observation wells installed at the core-hole sites. An average horizontal to vertical permeability ratio of about 1000 was determined.

Introduction

Western Energy Company's Rosebud Mine is located at Colstrip, Montana, approximately 50 km south of Forsyth and 200 km southeast of Billings. Figure 1 shows the location of past, current and future mine areas relative to Colstrip. The Rosebud coal seam of the Fort Union Formation is mined for use at Montana Power Company's mine mouth generation facilities and for export to mid-western customers. Material overlying the Rosebud coal, overburden, is stripped by means of 45 and 55 cubic meter coal shovels. Regrading is done by dozers with the help of graders for final smoothing. Sub-soil and topsoil are laid down by scrapers and the regraded and topsoiled surface is then seeded using standard farming techniques.

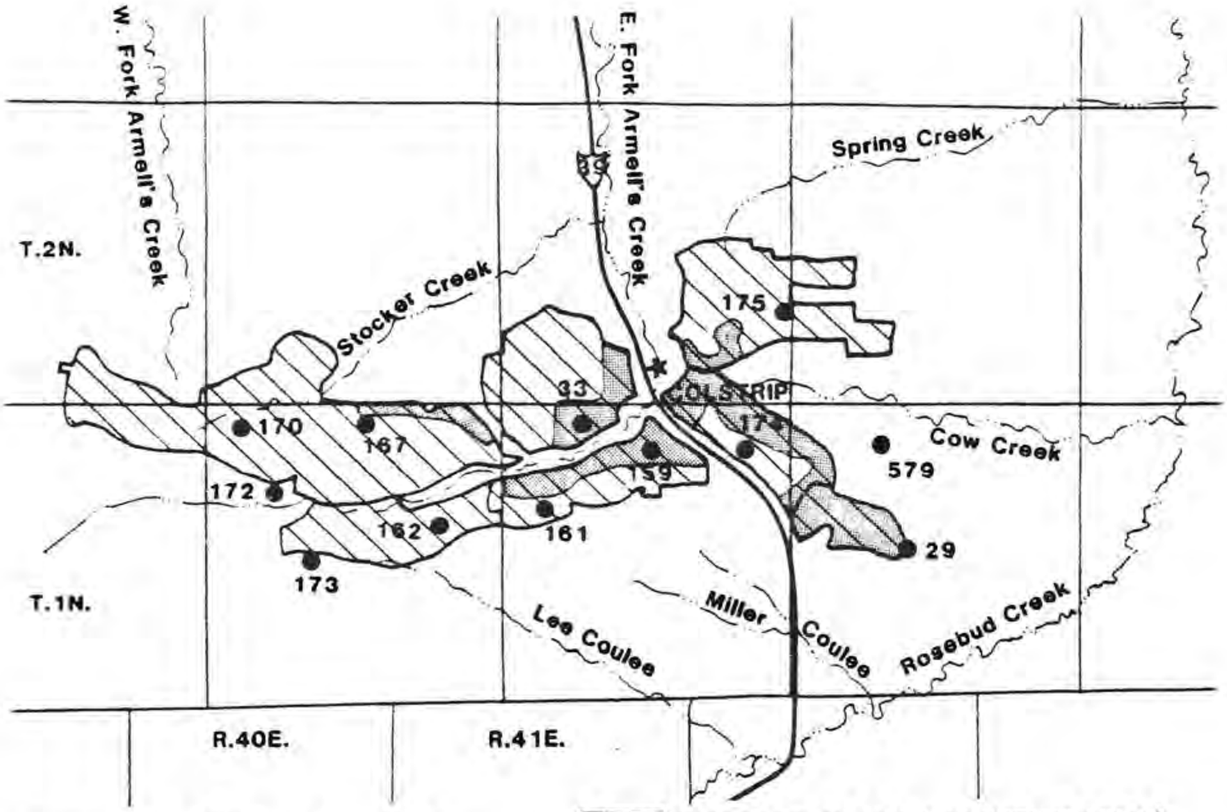


Figure 1. LOCATION MAP

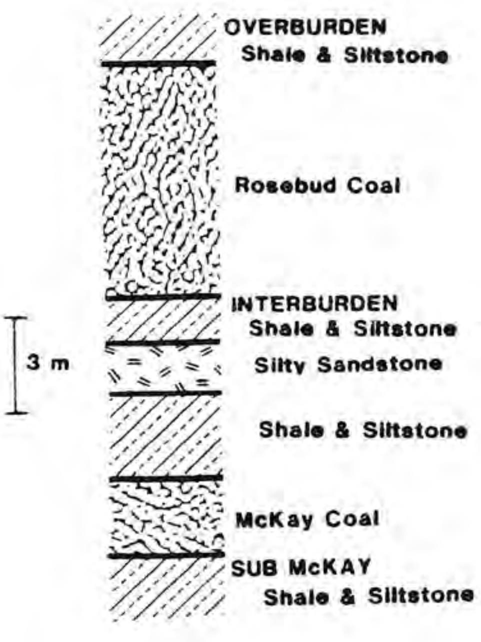


Figure 2. GENERALIZED LITHOLOGY

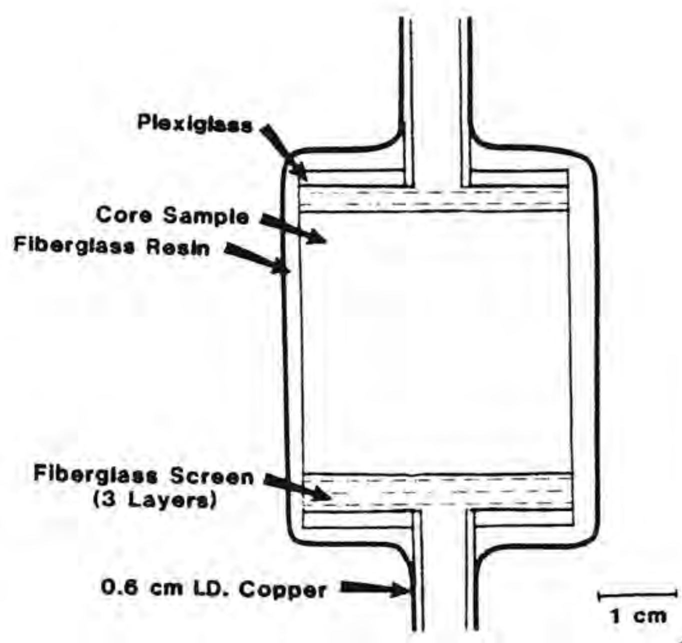


Figure 3. PERMEAMETER SCHEMATIC

The Rosebud coal seam is approximately 7.3 meters thick near Colstrip and is separated from the underlying McKay coal seam (2.4 meters thick) by 3 to 30 meters of interburden material consisting of shale, siltstone and lesser amounts of sandstone. The McKay coal seam is not mined at the Rosebud Mine because of ash, sulfur content, and BTU values.

BACKGROUND:

The Rosebud overburden consists generally of shales and siltstones and lesser amounts of sandstone. The Rosebud interburden, (generalized lithologic column shown in Figure 2) typically consists of shale and siltstone immediately below the Rosebud coal and immediately above the McKay coal. Carbonaceous shales are common at or near the contacts. Interburden may contain one or more very fine to fine grained sandstone layers. The Rosebud coal and McKay coal are both considered aquifers near Colstrip by virtue of their lateral continuity and aerial extent. Transmissivities and permeabilities for the Rosebud coal, McKay coal and post-mine spoils aquifer are given in Table 1. Typical well yields range from less than 3 to about 40 liters per minute for the Rosebud coal and from less than 3 to about 20 liters per minute for the McKay coal. Higher yields are encountered at isolated locations, although at many locations near Colstrip one or both coal seams may be dry. The potentiometric surface of the Rosebud coal is higher than that of the McKay coal by an average of four meters everywhere except very near the outcrop or active pits.

When the Rosebud coal is mined, overburden material from the next pass is placed or "spoiled" back into the preceeding pit. During this process, the overburden material is mixed thoroughly and the larger more competent

Lithologic Unit	Transmissivity Range sq cm/sec	Lognormal Mean Transmissivity (sq cm/sec)	Permeability Range (cm/sec)	Lognormal Mean Permeability (cm/sec)
Rosebud Coal	0.005-1.7	0.04	0.000007-0.002	0.00006
McKay Coal	0.001-0.2	0.05	0.000006-0.001	0.0002
Spoils	0.04-4	0.4	0.00009-0.006	0.0007

Table 1. Aquifer test data.

Aquifer	TDS Range (mg/l)	Average
Rosebud Coal *	270-5900	1500
McKay Coal *	340-5100	1800
Spoils	1100-6700	2900

* Includes only wells up-gradient of mining.

Table 2. Water Quality Data

PN/jm
DATA1.1

blocks roll down the spoil pile to form a "rubble" zone at the base of the spoils. This zone becomes the postmine aquifer. Water quality data for the Rosebud coal, McKay coal and spoils are summarized in Table 2.

Concern has been expressed in the past that as the spoils aquifer re-establishes the McKay might be impacted by downward leakage of spoils water through the interburden. This concern was based, in part, on vertical flow rates calculated using aquifer test data available at the time and Darcy's Law. These data were collected from wells which could be easily pumped (wells with significant thickness of sandstone) and represent primarily sand lenses within the interburden. In the mined-out portion of Western Energy Company's mine Area "A" immediately west of Colstrip, approximately 5 to 9 liters per minute may have moved horizontally through the overburden, the Rosebud and McKay prior to mining. Calculated postmine vertical flow through the interburden using aquifer test data, without accounting for shale and clay at the coal contacts is 1,000,000 liters per minute (K=0.006 cm/sec, A=400 hectares, I=0.7 cm/cm). This is not possible for an area recharged by direct infiltration from approximately 40 cm average annual precipitation.

It is well documented that horizontal permeabilities of sedimentary deposits are usually higher than vertical permeabilities. Published data suggest ranges of 10 to 1,000 for horizontal to vertical permeability ratios (Fetter, 1981; Freeze, 1969), but no specific information has been available for the Fort Union Formation. To assess ratios at the Rosebud Mine, laboratory permeameter studies and aquifer tests were conducted and methods of calculating vertical flows were examined.

Permeameter Studies

During the 1982 drilling season, 5 cm diameter cores were collected from several sites throughout the mine area. Coring started at the base of the Rosebud coal except for 3 sites, S-33 where coring started approximately 3 meters below the base of the Rosebud coal, S-29 where the core was collected from immediately above the McKay coal and 579 where a core was collected from below the McKay coal (Figure 4). In every case, except S-33, the cores consisted of primarily of siltstones and shales. The core collected at S-33 consisted entirely of fine to very fine grained sandstone. Core samples were cut to approximately 1.35 cm cubes which were encased in fiberglass resin, as shown in Figure 3. A porous membrane consisting of three layers of fiberglass screen was placed against the inflow and outflow faces of the core over which was placed plexiglass with a piece of 6 cm ID tubing inserted in a hole drilled through the plexiglass. Two samples from each core were prepared; one to measure vertical flow and one to measure horizontal flow.

Originally, it was planned to use a constant head permeameter with a head of between 80 and 90 cm of water. This translates to a gradient of approximately 20 to 25 cm/cm as opposed to natural hydraulic gradients of about .7 cm/cm across the interburden. However, when it was found that the samples were not saturated after 24 hours, a vacuum pump was used to add 60 cm of mercury at the bottom of the permeameters in addition to the 80 to 90 cm of water on the top. This arrangement gave a final total head of about 990 cm of water across the permeameters or a gradient of approximately 265 cm/cm. Flow rates were still so low that the evaporation rate,

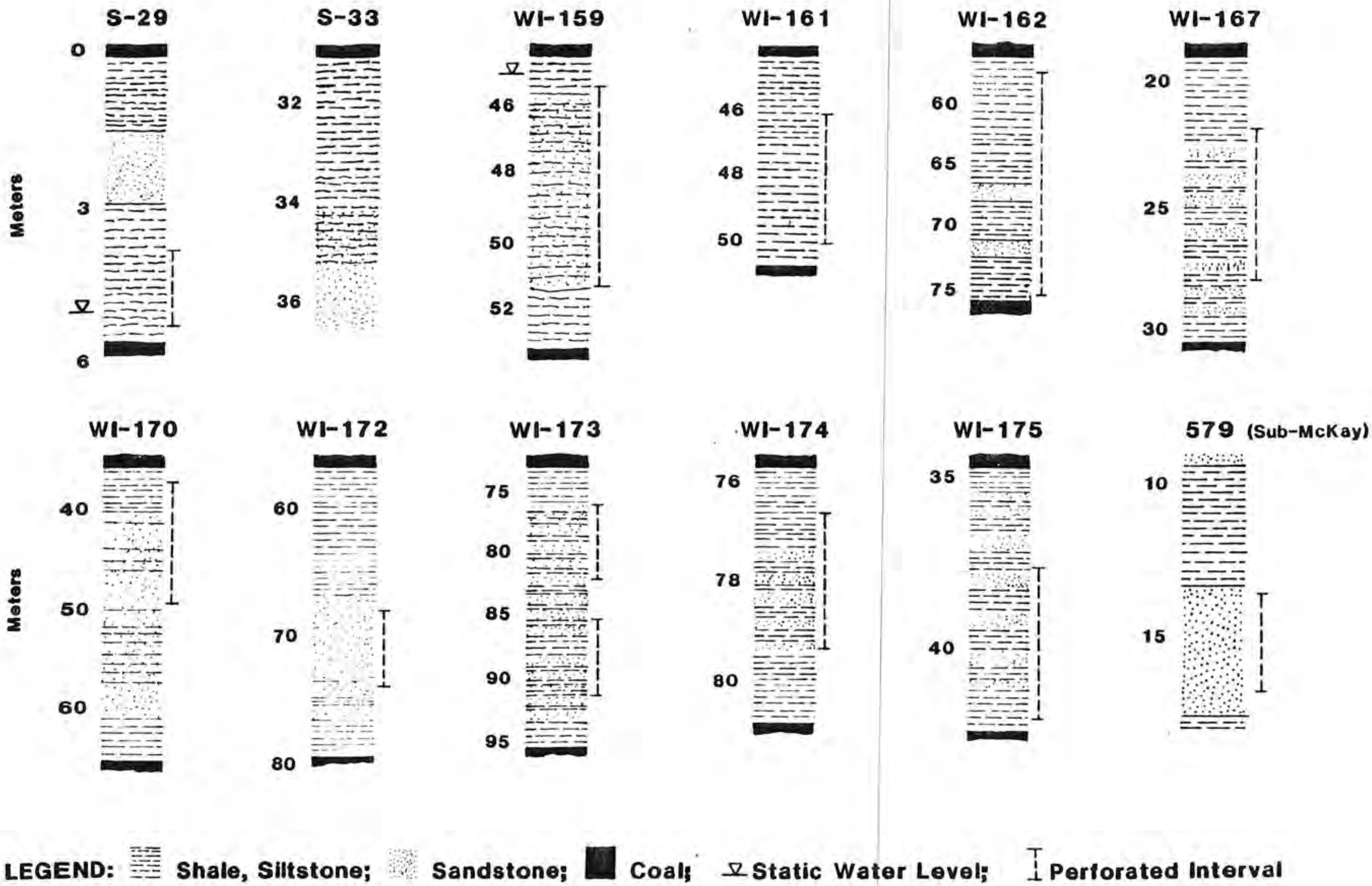


Figure 4. LITHOLOGIC SECTIONS FOR ROSEBUD - McKAY INTERBURDEN

under vacuum, at the outflow end of the permeameters was higher than the flow rates. In order to measure flow, therefore, the amount of water going into the permeameter had to be measured. This was accomplished by measuring the time for the water level in the clear plastic intake tube to drop over a short distance. A burette was used to measure the precise volume of water that is represented. Flow rates ranged from approximately 0.000014 to 0.015 ml/sec. In every case, the permeameter was completely saturated before starting the test. S-29 was the only permeameter that was tested without the vacuum pump. Under a gradient of approximately 23 cm/cm, a full week was required to pass 3 ml of water through the permeameter with the vertical orientation. By contrast, the permeameter with a horizontal orientation passed 400 ml in approximately 3 days. Permeameter results are tabulated in Table 3. For Rosebud-McKay Interburden, the laboratory data suggest a horizontal to vertical permeability ratio of approximately 8 using lognormal mean permeabilities. Horizontal permeability values ranged from 0.000000008 to 0.00001 cm/sec and vertical permeabilities ranged from 0.000000008 to 0.000003 cm/sec. Horizontal to vertical permeability ratios for lab data range from 0.4 to 127.

Aquifer Testing

Because cores were obtained almost exclusively from shales immediately below the Rosebud coal, they do not account for the sand lenses within the interburden. Aquifer tests, (constant drawdown or slug tests) were used to evaluate the horizontal permeabilities of sandstones. Interburden permeabilities measured by the aquifer tests ranged from 0.0000011 to 0.0035 cm/sec with a lognormal mean value of 0.00003 cm/sec (Table 3). Using the

	PERMEAMETER DATA			AQUIFER TEST DATA	
Site	Horizontal permeability cm/sec K(PH)	Vertical permeability cm/sec K(V)	Ratio K(PH)/K(V)	Permeability cm/sec K(H)	Ratio K(H)/K(V)
S-29-I	4.7E-06	2.8E-08	170		
S-33	9.7E-06	2.7E-06	4		
WI-159	3.5E-07	1.2E-08	28	1.7E-06	141
WI-161	5.0E-08	7.6E-09	7	5.5E-05	6148
WI-162	3.6E-07	8.1E-09	45	3.5E-03	402000
WI-167	8.2E-09	2.2E-08	0.4	1.1E-04	5023
WI-170	2.1E-08	2.0E-08	1	5.5E-06	279
WI-172	1.4E-07	3.4E-08	4	2.8E-05	839
WI-173	1.2E-07	1.2E-08	10	1.1E-06	95
WI-174	3.3E-07	1.4E-08	24	2.8E-05	2016
WI-175	1.7E-08	9.5E-09	2		
Lognormal Mean K	1.8E-07	2.4E-08	8	2.5E-05	1042
579	7.5E-08	6.5E-09	11	2.1E-05	3210

Table 3. Permeameter results and aquifer test data.

aquifer test data along with vertical permeabilities from permeameter tests yielded horizontal to vertical permeability ratios of between 95 and 402,000. A value of 1042 is obtained using lognormal mean horizontal and vertical permeabilities. Evaluation of aquifer test data by the Hantush modified technique (Lohman, 1972) suggested non-leaky conditions for three McKay coal wells and two interburden wells which could be pumped for sufficient time to apply the method. Evaluation of one additional interburden well suggested that the permeability of the interburden is several million times lower than that of the coal beds.

The interburden near Colstrip is not considered an aquifer because the sands are usually thin and discontinuous. Pumping rates for the aquifer tests were low, often less than 3 liters/minute and most test wells can not be pumped at all. In the case of S-29-1, where the zone tested is shale, recovery from a slug which raised the water level about one meter was so slow that the data could not be evaluated. Site S-33 is dry and cannot be tested but WI-175 will be tested and S-29-I will be retested.

Flow Estimates

Using the lognormal mean permeability from aquifer tests to compute the horizontal flow through Area A interburden yields a value of approximately 1.0 liter/min (T=0.013 sq cm/sec, W-2000 meters, I=0.007). Vertical flow through the interburden, using permeameter data, is calculated to be 40 liters/minute (K=0.0000000024 cm/sec, A=400 hectares, I=0.7). With an estimated horizontal flow of 1.0 liter/min, a vertical flow of 40 liters/minute is too high to maintain the observed mean water level difference across the interburden of 4 meters.

A method described by Fetter (1981) is being evaluated in an effort to provide a better solution. This method involves construction of permeability ellipses with horizontal and vertical axes proportional to the inverse of the square roots of the horizontal and vertical permeabilities respectively. A permeability ellipse for the Rosebud Mine based on data in Table 3, and the geometric construction to estimate the direction of a flowline is shown on figure 5. Fetter (1981) describes a method for computing the magnitude and direction of the hydraulic gradient vector using an L shaped array of wells or piezometers about 30 meters apart. Efforts to date, at the Rosebud Mine, have involved preliminary calculations with larger well spacings. The results suggest that the method cannot be applied unless the potentiometric surface under the array can be approximated by a smooth plane. Preliminary results for an array with a well spacing of about 1000 m, and an undulating potentiometric surface suggest a total flux through the interburden under 400 hectares in Area A of 1.0 liter/min and a vertical flow of a few milliliters/min. Further investigations are underway to try to determine if better estimates can be made from existing data, or if additional wells might be required.

Conclusion

Based on permeameter data and aquifer testing, the horizontal to vertical permeability ratio for the Rosebud McKay Interburden at the Rosebud Mine is 1042. Flow calculations for mine Area "A" suggest that the vertical permeability derived in this study cannot be directly applied using

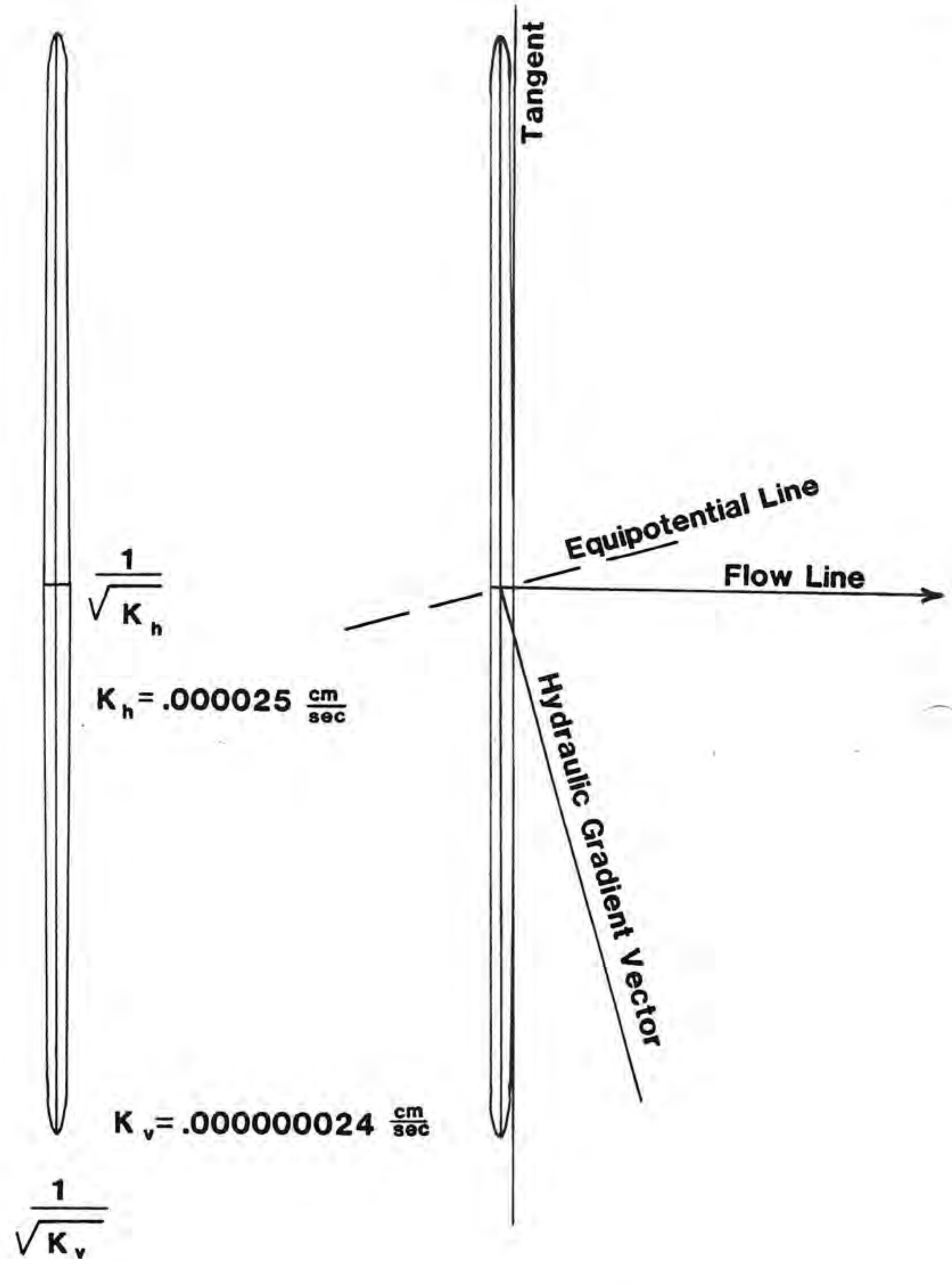


Figure 5. Permeability Ellipse for the Rosebud Mine & Approximate Flow Line for Mine Area "A".

Darcy's Law. A method proposed by Fetter (1981) shows promise although available data may not be amenable to the method.

REFERENCES

Fetter, C.W., 1981. Determination of the Direction of Groundwater Flow. Ground Water Monitoring Review, V 1, No. 3, pp 38-31.

Freeze, R.A., 1961. Theoretical Analysis of Regional Groundwater Flow. Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, Canada, 147 p.

Lohman, S.W., 1972. Ground-Water Hydraulics. United States Geological Survey Professional Paper 708, 70 p.

Accumulation of Metals and Radium-226 by Water Sedge Growing on Uranium Mill Tailings in Northern Saskatchewan

F.T. Frankling and R.E. Redmann, Department of Crop Science and Plant Ecology, University of Saskatchewan, Saskatoon S7N 0W0

ABSTRACT

The Lorado uranium mill tailings, near Uranium City, Saskatchewan are characterized by low pH, high salinity and high concentrations of elements such as copper, nickel, lead, uranium, vanadium and zinc. In 1982, we measured the concentrations of 30 elements in plant tissues of water sedge (*Carex aquatilis* Wahl.), a natural invader of wet tailings. Concentrations of copper, lead, uranium and vanadium in plants on the tailings were higher than in plants from background sites off the tailings. More detailed analyses of these elements in 1983 showed that relative concentrations in plant parts for all four metals were: roots > rhizomes > green leaves. Radium-226 and uranium were elevated in aboveground tissue (leaves) compared to samples from background sites off the tailings.

INTRODUCTION

The first uranium claims in the Uranium City area, staked in 1945 at Fish Hook Bay on the northern shore of Lake Athabasca, led to intensive exploration in the region. Mills at Lorado, Gunnar and Eldorado operated from 1957-60, 1955-63 and 1953-82 respectively, before abandonment (Woods 1981, Kupsch 1978).

The Lorado mill was designed to process 635 tonnes of ore per day from the Lorado mine and several other small mines, however this capacity was never fully realized. While in operation the mill processed a total of 545,000 tonnes of ore with an average grading of 0.24% U_3O_8. Ore composition varied greatly because of the diversity of sources. Ore was crushed to 60% minus 200 mesh and leached with sulphuric acid to dissolve the uranium minerals. Sulphuric acid was initially produced at the Lorado mill site using pyrite mined at the Lorado mine site, and later from sulphur shipped from Alberta (Whiting et al. 1982).

After removal of most of the uranium, the waste materials were pumped in a slurry to the waste disposal pond adjacent to Nero Lake. There were no presite disposal preparations and the tailing slurry (pH of 1.7-2.0) received no treatment prior to disposal. The tailings are acidic, saline and have elevated levels of several heavy metals including lead, uranium and vanadium (Kalin 1981). No stabilization of the tailings area (14.2 ha) has been attempted since the termination of the operation and exposed tailings material is subject to transport by air, surface and ground water (Swanson and Abouguendia 1981).

An additional problem associated with uranium mill tailings is the presence of radionuclides. Of particular concern are radium-226, radon, thorium-230 and lead-210. Some uranium and most of the radionuclides pass from the mill to the tailings area (Merritt 1971). Ripley and Redmann (1978) estimate that 14% of the total radioactivity is contained in the final processed concentrate, and 50 to 86% in the tailings, depending on the proportion of radon lost.

The entry of radionuclides into food chains is of particular concern in the case of uranium mining. Abouguendia et al. (1979) recorded elevated levels of U^{238}, Pb^{210} and Ra^{226} in meadow voles collected from a stand of sedges (Carex rostrata and C. aquatilis) and grasses over a uranium ore body in the Cluff Lake area of Saskatchewan. Meadow voles feed on insects, seeds and the vegetative parts of sedges, which dominate the site. Analysis of the sedges indicated elevated levels of U^{238}, Pb^{210} and Ra^{226}, which may have contributed to the elevated level of these elements in the meadow voles. Thus, tailings revegetation, although providing an effective means of reducing wind and water erosion, can create additional pathways for the movement of radionuclides and heavy metals into the biosphere.

Natural revegetation of the Lorado tailings site is sparce, and restricted to areas along the tailings edges. The main species include bluejoint (Calamagrostis canadensis), water sedge (Carex aquatilis), common cattail (Typha latifolia) and birch (Betula papyifera); secondary species are: Betula neoalaskana, Calamagrostis inexpansa, Equisetum spp., Festuca rubra and Salix planifolia (Swanson and Abouguendia 1981).

C. aquatilis is also a natural invader of uranium tailings in other regions of Saskatchewan and Canada (Harms 1982, Kalin and Caza 1982).

Densely tufted, with long creeping rhizomes, it occurs throughout Canada, commonly growing in slough margins, river flats, marshes and wet meadows (Moss 1983, Porsild and Cody 1980).

The objectives of this study were twofold: (1) to determine if C. aquatilis growing at the tailings site accumulated elevated levels of heavy metals and radionuclides; and (2) to determine if metals and radionuclides were concentrated in particular plant parts.

MATERIALS AND METHODS

Sampling Procedure

Samples of C. aquatilis were collected from the Lorado mill tailings site and the Uranium City area in August 1982 and June 1983. Tailings and soils were collected from the root regions of sample plants. Plant samples collected in August 1982 were separated into leaves and a composite of roots and rhizomes. Samples collected in June 1983 were separated into three fractions: leaves, roots and rhizomes.

Sample Analysis

Oven dry (105°C) plant material, tailings and soils collected in 1982 were analyzed for 30 elements using plasma emission spectroscopy. Samples collected in 1983 were analyzed for copper, lead and vanadium using atomic absorption spectroscopy, for uranium using delayed neutron counting and for radium-226 using alpha counting.

Tailings and soils were air dried and sieved to remove particles greater than 2mm. Hydrogen ion activity (pH) and conductivity were determined in a 1:1 mixture of 20 g of air dry material and 20 ml of deionized distilled water agitated for 1 h. Moisture content was determined after a fresh weight sample was oven dried at 105°C for 24 h. Available sulphate was extracted by agitating 25 g of sample with 50 ml of 0.001M $CaCl_2$ for 0.5 h. The extract was analyzed for sulphate using atomic absorption spectroscopy. Particle size analysis was performed using the hydrometer method (Boyoucos 1951).

An unpaired t-test (0.05 level, population variances assumed unequal) was used to compare element concentrations in tailings, soils and vegetation samples from on and off the site. This test was also used to compare concentrations in different plant parts.

RESULTS

Some of the ores milled at Lorado contained pyrite which when exposed to the environment is oxidized producing sulphuric acid. This and the use of sulphuric acid in the milling process has resulted in acidic conditions and extremely high available sulphate levels throughout the tailings site (Table 1). According to Richards' (1954) classification of saline soils, the tailings site is moderately saline. Tailings contained less sand and more silt and clay than local soils. Available nitrogen, phosphorus and potassium levels were very low while copper and zinc levels were elevated in tailings compared to soils vegetated with C. aquatilis (Frankling 1984).

Tailings and soils from the root regions of C. aquatilis were analyzed for 30 elements in 1982. Tailings had significantly higher concentrations of several elements including copper and lead, compared to soils in the Uranium City region (Table 2). In 1983, elevated concentrations of copper, lead, radium-226, uranium and vanadium were observed in tailings, compared

Table 1. Chemical and physical characteristics of tailings and soils from the root regions of *C. aquatilis*.

	pH	Conductivity (mS cm^{-1})	Moisture Content (%)	S - SO_4^{-2} (μg g^{-1})	Sand	Silt (%)	Clay
Tailings	3.6(4.0)*	3.4(1.2)*	27.6(7.5)	2400(1860)*	56.1(22.1)*	37.7(21.6)*	6.0(2.4)*
Soils	5.6(5.7)	1.5(1.5)	48.1(38.3)	420(260)	91.0(2.5)$^{\Delta}$	6.0(2.1)$^{\Delta}$	2.9(0.5)$^{\Delta}$

*Significant difference (0.05 level) between tailings and soil

$^{\Delta}n = 6$

Table 2. Concentrations of elements[1] in tailings and soils from the root regions of C. aquatilis collected in 1982.

Element	Tailings ($n^2 = 4$)	Soils ($n = 4$)	Significance level
	($\mu g\ g^{-1}$ oven dry wt)		
Al	56500 (7593)	14550 (6681)	.0004*
B	12.6 (47)	77 (16.4)	.0054*
Ba	502 (69)	100 (41)	.0006*
Ca	17600 (19675)	30650 (1837)	.2783
Cr	116 (28)	21.5 (8.8)	.0083*
Cu	645 (256)	12.5 (6.4)	.0161*
Fe	43750 (11176)	12517 (8711)	.0126*
K	5925 (1654)	3625 (1406)	.0876*
Mg	9725 (1105)	6550 (2693)	.1172
Mn	235 (73)	87 (30)	.0334*
Na	26250 (6291)	5312 (332)	.0069*
Ni	239 (141)	14.5 (2.3)	.0839
Pb	330 (121)	12.9 (3.4)	.0458*
Ti	2875 (512)	438 (180)	.0029*
Zn	465 (210)	100 (53.6)	.048 *
Zr	260 (84)	NA[3]	-

[1]The following elements were below detection limits in tailings: Ag, As, Au, Be, Cd, Co, Mo, P, Sb, Se, Th, U, V and W.

[2]Sample size

[3]Not analyzed

*Indicates significant difference (0.05 level) between tailings and soil.

to soils vegetated with C. aquatilis (Table 3).

Several elements including lead, uranium and vanadium appear to be elevated in roots/rhizomes from the tailings site compared to the background sample (Table 4). Leaves of C. aquatilis collected from the tailings site had higher concentrations of several elements including nickel, lead and uranium compared to background samples, however, manganese was the only element to be significantly elevated in leaves from the tailings site based on statistical tests. After entering C. aquatilis plants, elements appeared to accumulate in belowground tissue. Aluminum and iron were significantly higher in roots/rhizomes than leaves collected at the tailings site, and several other metals, including copper, lead, uranium and vanadium displayed a similar trend, although not statistically significant (Tables 4 and 5).

Roots and rhizomes of C. aquatilis from the tailings site had relatively higher concentrations of copper, lead, vanadium and particularly uranium compared to samples collected in the Uranium City area (Table 6). A comparison of copper and lead concentrations in C. aquatilis leaves collected on and off site indicated no significant differences (Table 6). Uranium and radium-226 concentrations were elevated in leaves collected at the tailings site (significant at the 0.05 and 0.08 levels respectively).

A comparison of roots, rhizomes and leaves was performed to determine where in plants elements were accumulating. Vanadium was statistically higher at the 0.05 level in aboveground tissue (leaves) compared to belowground tissue (roots) (Table 7). However, lead and uranium also appear to accumulate in roots compared to leaves. Differences in metal levels between roots and rhizomes and rhizomes and leaves are less evident (Table 7). The general trend is for element concentrations to decrease in the order: roots > rhizomes > leaves.

Table 3. Concentrations of elements in tailings and soils collected in 1983.

	Cu	Pb	U	V	Ra-226 (Bq g^{-1} Oven dry wt.)
	($\mu g\ g^{-1}$ Oven dry weight)				
Tailings (n^{1}=4)	71(18)	307(145)	112(43)	430(158)	26.5 (12.0)
Soils (n=4)	22(4.3)	11.5(5.8)	6.6(2.5)	55(17.3)	.24(.17)
Significance level	.0146*	.0266*	.0167*	.0183*	.0224*

[1]Sample size

*Significant difference (0.05 level) between tailings and soil.

Table 4. Concentrations of elements[1] in roots and rhizomes of *C. aquatilis* collected in 1982.

Element	Tailings site (n^2=4)	Background area (n=1)
	($\mu g\ g^{-1}$ Oven dry weight)	
Ag	.6(.2)	.1
Al	667(122)	900
B	7.2(3.7)	7
Ba	10.6(2.2)	28
Be	.4(-)	.7
Ca	860(157)	1900
Co	3(1.8)	2.3
Cr	3.1(1.3)	3
Cu	21(9.8)	10
Fe	1500(522)	3000
K	6875(573)	5800
Mg	1675(573)	930
Mn	182(43)	190
Na	355(189)	340
Ni	8.6(5)	5
P	1087(154)	970
Pb	21(10)	6
Se	40(-)	1
Ti	6.9(2.2)	52
U	63(65)	3
V	12.5(2.8)	4
Zn	24(29)	29
Zr	1.3(.4)	1.4

[1]The following elements were below detection limits in tailings: As, Au, Cd, Mo, Sb, Th and W.

Table 5. Concentrations of elements[1] in leaves of C. aquatilis collected in 1982.

Element	Tailings site (n^2=4)	Background area (n = 4)	Significance values: Leaves on site-off site	Significance values: Roots/rhizomes - leaves on site
	(μg g^{-1}Oven dry wt.)			
Ag	1.6(2.3)	< .1(–)	–	.4858
Al	247(92)	132(50)	.0931	.0031*
B	17(7.4)	31.2(3.5)	.0261*	.0796
Ba	6.1(2.8)	15.2(2.2)	.0038*	.0563
Be	.5(–)	.2(–)	–	–
Ca	2325(464)	4400(374)	.0009*	.0094*
Co	1.4(0.8)	.48(–)	–	–
Cr	1.1(0.4)	2.4(1)	.1059	–
Cu	12.7(3.8)	8.4(2.3)	.4926	.1945
Fe	305(86)	205(57)	.1131	.0204*
K	10175(2275)	10800(1036)	.6433	.0587
Mg	2765(1602)	1475(95)	.2319	.3248
Mn	710(200)	77(22)	.0082*	.0143*
Na	267(167)	350(21)	.4009	.5203
Ni	5.9(3.4)	1.6(1.2)	.1017	.4714
P	1067(47)	1227(400)	.4854	.8207
Pb	6.8(4.3)	1.6(1.1)	.1061	.0617
Ti	1.4(0.1)	2.8(1.1)	.8060	.0159*
U	19.6(22)	0.3(.08)	.2813	.3044
V	2(–)	< 2(–)	.5443	.5188
Zn	29(24)	37.5(2.6)	–	–

[1]The following elements were below detection limits in tailings: As, Au, Cd, Mo, Sb, Se, Th, W and Zr.

[2]Sample size.

*Indicates significant difference (0.05 level) between on and off site samples.

Table 6. Concentrations of elements in roots, rhizomes and leaves of _C. aquatilis_ collected in 1983.

Location	Plant part	Cu	Pb	U	V	Ra-226 (Bq g^{-1} Oven dry wt)
		($\mu g\ g^{-1}$ Oven dry wt.)				
Tailings site	roots ($n^{1} = 3$)	61 (24)	19.3(5.6)	252(138)	19.6(4.0)	NA[2]
Background area	roots (n = 2)	11 (8.4)	7.0(4.2)	0.6(0.1)	<5.0	NA
Tailings site	rhizomes (n = 4)	34.5(8.8)	13.7(7.0)	148(106)	15.7(8.7)	NA
Background area	rhizomes (n = 2)	4.4(3.0)	7 (0)	0.5(0.07)	<5.0	NA
Tailings site	leaves (n = 4)	26.5(13)	9 (5.3)	61(39)	6.2(1.5)	0.13(0.07)
Background area	leaves (n = 4)	14.5(2.5)	5.1(2.1)	0.26(0.05)	<5.0	0.03(0.
Significance level	leaves	0.1750	0.4863	0.0518	-	0.0749

[1]Sample size, except U: n = 4.

[2]Not analyzed.

Table 7. Accumulation ratios (ARs) for roots, rhizomes and leaves of C. aquatilis growing at the Lorado tailings site, collected in 1983.

AR	Element			
	Cu	Pb	U	V
Rhizomes / roots	0.56	0.70	0.58	0.80
Leaves / rhizomes	0.76	0.65	0.41	0.39
Leaves / roots	0.43	0.46*	0.24*	0.31**

*Significant difference between levels in roots and leaves at the 0.10 level.

**Significant difference between levels in roots and leaves at the 0.05 level.

DISCUSSION AND CONCLUSIONS

A number of trace elements, including arsenic and vanadium, are frequently enriched in uranium ore deposits. Other trace metals, including copper, nickel and zinc are also often enriched due to the presence of base metal sulphides associated with pyrite (Dressen et al. 1982). Tailings beneath C. aquatilis growing at the site had elevated concentrations of several metals, including copper, lead, uranium and vanadium. The radionuclide radium-226 was also elevated in tailings.

Belowground tissue of C. aquatilis growing at the tailings site had elevated levels of copper, lead, vanadium and particularly uranium compared to background samples. Copper, uranium and vanadium values were also higher than values considered normal for land plants, as reported in Bowen (1979). Lead concentrations were similar to values for land plants.

Aboveground tissue of C. aquatilis growing at the tailings site had elevated levels of uranium and radium-226 compared to background samples. Uranium levels also were elevated compared to reported values for Carex spp. (<3.0 $\mu g\ g^{-1}$ ash weight) growing near uranium anomalies on the Precambrian Shield (Sheppard et al. 1981), and in C. aquatilis and C. rostrata (0.04-1.2 and 0.04-7.0 $\mu g\ g^{-1}$ ash weight respectively) growing adjacent to Cluff Lake, Saskatchewan in the vicinity of the Cluff Lake uranium mine (Abouguendia et al. 1979). Radium-226 values in leaves were similar to values for aboveground tissue of C. aquatilis (0.001-0.921 Bq g^{-1} ash weight) and C. rostrata (0.004-0.307 Bq g^{-1} ash weight) growing in the Cluff Lake area (Abouguendia et al. 1979). Concentrations of copper, lead, uranium and vanadium in plants growing at the tailings site tended to decrease in the order: roots > rhizomes > leaves. This is in agreement with the behaviour of lead in ryegrass and uranium in barley (Jones et al. 1972, Van Netten and Morley 1983).

In conclusion, copper, lead, uranium, vanadium and radium-226 levels were elevated in C. aquatilis growing at the tailings site. Belowground tissue provides an effective barrier to the movement of elements to aboveground plant parts, and only uranium and radium-226 appeared to be elevated in aboveground tissue. The presence of these two elements in leaves of C. aquatilis suggests that further study on their fate is appropriate in tailings areas in Canada where this species is growing.

ACKNOWLEDGEMENTS

The authors wish to thank the Saskatchewan Research Council and the Northern Scientific Training Grant Program for financial support of this work.

REFERENCES

Abouguendia, Z.M., R. Barclay, J. Polson, W. Sawchyn, P. Jones and J. Whiting. 1979. Additional environmental baseline studies for the Cluff Lake area, Sask. Report No. C79-19, Sask. Res. Council, Saskatoon.

Boyoucos, G.J. 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. Agron. J. 43: 434-438.

Bowen, H.J.M. 1979. Environmental chemistry of the elements. Acad. Press, New York.

Dreesen, D., J. Williams, M. Marple, E. Gladney and D. Perrin. 1982. Mobility and bioavailability of U mill tailings conterminants. Envir. Sci and Tech. 16(10): 702-709.

Frankling, F.T. 1984. Limitations to plant establishment on acidic uranium mill tailings in northern Saskatchewan. M.Sc. thesis. 128 pp.

Harms, V.L. 1982. A plant taxonomic survey of the Uranium City region, Lake Athabasca north shore, emphasizing the naturally colonizing plants on uranium mine and mill wastes and other disturbed sites. A report submitted to the Sask. Dept. of Envir. TWPFH Report No. 82-1.

Jones, L.H.P., C.R. Clement and M.J. Hopper. 1973. Lead uptake from solution by perennial ryegrass and its transport from roots to shoots. Plant Soil 38: 403-414.

Kalin, M. 1981. A preliminary assessment of the environmental conditions of two abandoned uranium mill tailings sites in Saskatchewan. Report to Sask. Envir. and Envir. Canada (EPS), Regina.

Kupsch, W.O. 1978. From Erzgebirge to Cluff Lake - a scientific journey through time. Musk-ox No. 23.

Merritt, R.C. 1971. The extractive metallurgy of Uranium. Johnson Public. Co.

Moss, E. 1983. Flora of Alberta. University of Toronto Press, Toronto.

Porsild, A.E. and W.J. Cody. 1980. Vascular plants in continental Northwest Territories, Canada. National Museums of Canada, Ottawa.

Richards, L.A. (ed.) 1954. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Handbook #60.

Ripley, E.A. and R.E. Redmann. 1978. Environmental impact of mining in Canada. Centre for Resource Studies, Queens Univ., Kingston, Ont.

Sheppard, M.I., L. Olchowy and K.R. Mayoh. 1981. Uranium, thorium, radium and arsenic concentrations of plants and soils of the precambrian shield: a preliminary study. Envir. Res. Br., Whiteshell Nuclear Res. Est., Pinawa, Manitoba.

Swanson, S. and Z. Abouguendia. 1981. The problem of abandoned uranium tailings in northern Saskatchewan - An overview. Publ. No. C-805-48-C-81, Sask. Res. Council, Saskatoon.

Van Netten, C. and D.R. Morley. 1983. Uptake of uranium, molybdenum, copper and selenium by the radish from uraniun-rich soils. Arch. Environ. Health 38: 172-175.

Whiting, J., E. Christiansen, H. Heuser, J.S. Kermeen, H. Maathuis and P. Machibroda. 1982. Summary report on the surface water and groundwater investigations of the Lorado mill area and meteorology data for the Gunnar Uranium tailings. Vol. 1. Sask. Res. Council Publ. #E-820-4-E-82.

Woods, R.J. 1981. A review of present research, research needs and research capabilities relating to the uranium mining and milling industry in Saskatchewan. Report to Mines Pollution Control Branch, Sask. Environ., Regina.

A METHODOLOGY FOR ASSESSING PRE-MINE AGRICULTURAL PRODUCTIVITY

T.A. ODDIE, D.R. DORAM, H.J. QUAN

MONENCO CONSULTANTS LIMITED, TRANSALTA UTILITIES CORPORATION

ABSTRACT

Current requirements set out by the Alberta Government state that the goal of reclamation is to return mined land to a capability that is equivalent or better than that which existed prior to mining. In preparation for coal strip-mine activity in the Lake Wabamun area, Monenco Ltd. has been conducting agricultural field studies for TransAlta Utilities Corporation since 1977. These studies are conducted to quantify land productivity as a general indicator of land capability prior to mining for comparison to productivity on reclaimed land. A close association with rural community groups and land holders is maintained to ensure success and reduce interference with local farm activities.

Agricultural land is generally differentiated into major crop and soil types with the use of maps, aerial photographs and field surveys. Field sites are selected for monitoring in relative proportion to the occurance of the major crop and soil types within the study area. Potential field sites are assessed on the basis of land use, uniformity of soil type and slope, and accessability.

Sampling methodologies for major crop types such as pasture, hay and grain have been adapted over time to reduce variability encountered during field programs. A review of past research has been undertaken to develop a statistically valid methodology for measuring productivity, with specific emphasis on pastureland monitoring.

INTRODUCTION

Coal strip-mine activity by TransAlta Utilities Corporation in the Lake Wabamun, Alberta area has been conducted for the production of electrical power since 1962. The mine area is located approximately 80 km west of Edmonton, with mine activity occurring both north and south of Wabamun Lake. The area north of the lake includes the Whitewood Mine permit area and Wabamun thermal power plant, encompassing 4700 ha of land (TransAlta Utilities Corporation, 1983). The area south of the lake includes the Highvale-north mine permit area and Sundance thermal power plant, encompassing 6475 ha, and the Highvale-south mine permit area and Keephills thermal power plant, encompassing 5787 ha of land (Montreal Engineering Company Limited, 1979b).

Mining is currently in progress within both the Whitewood and Highvale-north mine areas and is expected to begin in the Highvale-south mine area within the next ten to twenty years. Current government Development and Reclamation requirements state that the goal of reclamation is to return mined land to a capability that is equivalent or better than that which existed prior to mining. Monenco Limited has been conducting agricultural field studies for TransAlta Utilities Corporation since 1977 in order to quantify productivity of land used for agriculture. These measurements of pre-mine land productivity, which are a general indicator of land capability, are part of the approach that TransAlta uses to document the success of its reclamation efforts.

METHODOLOGY

BACKGROUND

The methodology presently used for the determination of agricultural productivity is the result of a continuous review of related research in conjunction with an adaptable field program to help reduce variability encountered in the area. This adaptation occurred over the years to develop a statistically valid methodology for measuring agricultural productivity without creating unnecessary interference with current farming activities. Additionally, the methodology is designed to be as cost effective as possible. A cooperative association has been maintained with the local landholders and rural community groups to ensure that the project objectives were well understood. Results of soil analysis and crop yields have also been made available to the local land holders to assist in their field management activities. The yearly field management activities of each field involved in the study are documented on questionnaire handouts delivered in the spring of each year. The farmers are requested to supply information regarding seeding, fertilizing, crop rotation and other field related activities. Since the inputs of farm management have an affect on productivity, it is important to qualitatively monitor the influence of this factor.

LAND EVALUATION

Agricultural land within each mine permit area was assessed by reviewing available information from previous soil and vegetation surveys, soil maps, and aerial photographs. The crop type and soil characteristics were considered to be major factors in the determination of land productivity, so the dominant crop and soil types were differentiated from this information. This differentiation was completed so that similar crop and soil conditions could be identified on reclaimed land and compared to pre-mine agricultural productivities.

The relative proportion of each soil subgroup was determined by planimetering the area covered by each subgroup in the study area on a soil survey map. The proportion of major crop types found in the area was determined in a similar manner, using recent color aerial photographs from the study area. Vegetation observed in the study area was easily differentiated into agricultural land and wildland, but a field survey was often required to differentiate the area into more specific crop types such as coarse grains, hay, tame pasture and wild pasture. In order to ground-truth these unidentifiable crop types within the study area, observations were made from municipal roadways and crop types were noted on color mosaic maps of aerial photographs. The relative proportion of each major crop type was then determined.

SAMPLE SIZE ESTIMATION

The number of field sites selected to monitor the study area was influenced by the number of major soil and crop types noted in the area. In the Highvale-south mine permit area, for example, the proportion of major crop types were determined to be 50% tame pasture, 25% hay and 25% coarse grains, while the major soil types were determined to be 60% Luvisol, 20% Gleyed Luvisol and 20% Gleysol. With this in mind, it was concluded that the field sites selected for monitoring the study area should represent a sampling range of similar proportion. A total of ten field sites were considered a suitable number to study the area, including five field sites on pasture and five field sites on hay or grain. The field sites located on hay or grain rotate as crop rotations progress. Similarily, of the ten field sites selected to study the area, six field sites were located on Luvisol soils, two field sites on Gleyed Luvisol soils and two field sites on Gleysol soils.

An analysis of data collected in a similar program was completed to determine the number of samples required to monitor each individual field site, as well as determine if field sites with similar crop and soil types could be considered replicates of each other (Monenco 1983a).

The analysis indicated that ten samples collected from each individual field site could be used to accurately monitor productivity with a confidence limit of at least 90% and an allowable error of ±20%.

FIELD SITE SELECTION

Potential field sites were identified during a late fall and early spring field survey. The survey was conducted from municipal roadways to identify potential sites on the basis of land use, uniformity of soil type and slope, and accessibility. Municiple roadways were used to locate most of the field sites to ensure access throughout the growing season and to help reduce crop disturbance created by repeated trips to the field sites. The determination of specific crop type was completed in the fall when hay and grain harvests were in progress. Consideration was also given to the consistency of slope position to help reduce variability encountered between north-facing slopes south-facing slopes and relatively flat areas. The spring field survey was used to confirm soil types identified on soil maps or in previous soil surveys. Since fields were still either un-seeded or crops very small at this time, access was not difficult to arrange. Soil samples were collected from random locations across each potential field site with a Dutch soil auger. Relevant soil characteristics from the major horizons, such as color, texture, mottling and gleying, were used to confirm the identity of the soils.

From the overall list of potential field sites, ten final selections were made. Land holders were contacted to relay the objectives of the program, to determine their interest in participating in the program and to inquire about their long term land use plans. Alternate field sites were selected when farmers declined participation in the monitoring program.

VEGETATION SAMPLING PROGRAM

The sampling methodology is based on sampling procedures previously completed in the Lake Wabamun area (Montreal Engineering Company, Limited 1979b, Monenco Limited 1982a, 1983b, 1983c, 1984). The methodology was finalized after a review of literature on statistical sample size estimation (Webster 1979, Little and Hills 1978, Payandeh and Beilhartz 1979, Freese 1967), sampling procedures for measuring productivity (Nevens and Khulman 1935, Mott _et al_. 1962, Cooke 1969, Bjorge 1976, Mueggler 1976, Agriculture Canada 1981, Ahmed _et al_. 1983, Kondra 1983, Lopitinsky 1983, Waddington 1983), experimental variability factors (Van Dyne _et al_. 1963, Warren and Mendez 1982, Deshmukh and Baig 1983), the effect, use and design of pastureland monitoring cages (Williams 1951, Cowlishaw 1951, Green _et al_. 1952, Linehan 1952, Campbell and Lodge 1955) and the effects of grazing on pasture fields Pitt and Heady 1979, Hofmann _et al_. 1981).

PASTURELAND MONITORING

Estimates of productivity on pastureland are determined by measuring plant matter produced on selected field sites over each growing season. Small prismatic wire cages, each measuring 2 meters long, 1.5 meters wide at the base, and 1 meter high, are utilized to protect small areas of pasture grass within each field so that measurements of plant growth can be made. The cages are constructed of 5 x 5 cm, 9 gauge galvanized wire mesh, strong enough to withstand cattle activities, and are secured to the ground with metal pegs. A total of 10 cages are randomly placed to sample within the boundaries of each 1 ha field site. Pasture grass under each cage is cut three times during the growing season with a sickle-bar mower. The first harvest date coincides with the entry of cattle onto the pastures, the second occurres before the grass heads out in July, and the final cut occurs by mid-September.

A bulk sample from a 1 x 2 m area is cut at approximately 5 cm from the ground and collected from the cages during each harvest. Borders of 0.25 m along the sloped sides of each cage are not included in the sample to reduce any effects created by cattle grazing along the edges. Each sample is raked, placed in a paper bag, and weighed to the nearest gram on a triple-beam balance. A small grab sample is collected from every second bulk sample, weighed to the nearest gram and sent to the laboratory for drying and dry weight measurement. The fresh weight/dry weight ratio from these selected grab samples is used to determine the dry weights for all the bulk samples. Measurements obtained during the three harvests at each cage are combined, and an average measurement for each field determined and reported in g/m^2 and tons/acre.

In the earlier years of pasture land monitoring, a permanent fenced exclosure was used to monitor each field site. This system, however, did not have the advantage of mobility that the present cage monitoring system has. Over time, changes in the plant community within the permanent exclosure were occurring. The lack of normal grazing pressure by cattle was affecting productivity. In addition, the permanent exclosures were more susceptible to cattle damage than the cages. Therefore, the cage monitoring system applies a more reliable and consistant sampling technique, and allows replicated sampling across the entire field site. A "direct" sampling method, which measures the grass produced under each cage for the entire growing season, is utilized for this monitoring program. A "difference" sampling method, which measures growth, both inside and outside of each cage, would be required if measurements of grass consumption by cattle were being monitored.

HAYLAND MONITORING

Estimates of productivity on hayland are determined by measuring plant matter produced on selected field sites over each growing season, prior to the summer (1st cut) and fall (2nd cut) harvest. Ten hay samples are collected from each field site, with a 25 m interval between each sample and a total field site area measuring 50 m wide x 125 m long. A pre-determined sampling interval, rather than a completely random selection of sample locations, is used in an effort to minimize crop disturbance and assist in re-locating sample sites. A hay sample from a 1 m^2 area is cut from each sample location at approximately 5 cm from the ground with hand-operated hedge clippers and is forwarded to the laboratory for determination of fresh weight/dry weight ratios.

In the spring, when hay growth is short, each of the ten sample locations are identified with a 1 m high white stake. After the first sampling program is completed, the stakes are removed and each sample location is marked with a small amount of colored flagging tape. After the field is swathed and baled, the sample locations are reidentified, and the flagging is replaced by 1 m high white stakes. This process allows the same locations to be easily identified for the second sampling program. Measurements obtained during the first and second sampling program from each sample location are combined. An average measurement for each field is determined and reported in g/m^2 and ton/acre. The plant composition of each hayfield is determined by estimating the occurrence of different plant species at each of the 10 sample locations using the point-intercept method (Mueller-Dombois and Ellenberg, 1974).

An attempt at an alternative sampling method was conducted for one season, but it proved highly variable and inconvenient. Fresh weight samples were collected directly from farmer swaths as soon as possible after the hay was cut. The coordination of this sampling method was made difficult by the fluctuating schedules of both the researcher and the farmer. There was also a problem with accuracy of the measurement, considering all hay crops are not cut at a consistent height, width, or time. The present sampling methodology allows for much more control by the researcher, thereby eliminating a large percentage of the variability.

GRAINLAND MONITORING

Estimates of productivity on grainland are determined by measuring plant matter produced on selected field sites over each growing season, prior to fall swathing and combining. The sampling procedure is the same as the Hayland sampling program discussed previously. When dry, each sample is weighed to determine total weight of grain and straw, threshed on a portable threshing machine and the grain collected in a paper bag and weighed. This provides a dry weight measurement for both grain and straw at each sample location.

In the spring, after seeding is complete, each of the ten sample locations are identified with a 1 m high white stake. This allows quick and easily identification of sample locations without unnecessary disturbance of the mature crop.

An average measurement for grain and straw is determined for each field. Grain samples are sent to the laboratory for determination of moisture content. Field conditions, such as grain lodging and weed problems, are noted when samples are collected.

Large 15 m x 15 m permanent plots had previously been used to monitor coarse grains, but these were found extremely inconvenient for the farmer to identify and cut around.

SOIL SAMPLING PROGRAM

The identification of individual field site soil characteristics plays an important role in the assessment of baseline conditions associated with each crop and soil type. Where no previous soil survey information is available, a soil pit is dug in a central location within each field site after the fall harvest. The timing helps minimize any effects on that years crop, yet provides time to re-seed the surface for next seasons growth. The soil from each major horizon ($\geq$ 5 cm) is identified, described and sampled (McKeague 1978). Samples are sent to the laboratory for chemical and physical analysis.

When more in-depth sampling is required, composite hand auger samples are collected in the spring in addition to the fall soil pit. Samples from ten random locations at three depths in each field site (0-15 cm, 15-30 cm and below 30 cm) are collected, placed in labelled plastic bags and sent to the laboratory for chemical analysis. Information regarding available nutrients from the spring and fall soil analysis are made available to the farmer associated with each field site.

CONCLUSION

Although methods for sampling soil and vegetation can be quite specific, a certain degree of flexibility was maintained to develop this monitoring program. A mixture of recognized sampling techniques, practicality, and field experience are used to adapt the program within a variety of conditions. The program utilizes crop yield to measure productivity on the dominant soil types in the area. This information is supplemented by farm management data provided by farmers. The process of undertaking the surveys includes land evaluation, sample size estimation, site selection combined with public participation, soil sampling and vegetation sampling. The information collected will provide an accurate measurement of pre-mine land productivity and a useful indication of land capability.

ACKNOWLEDGEMENTS

The orignal projects and the preparation of this review was funded by TransAlta Utilities Corporation. Field work data analysis and report preparation was conducted by Thomas Oddie (agronomist). Project Management was provided by Leslie Panek (Senior Supervising Reclamation Specialist - Monenco), P.A. Lulman (Reclamation Supervisor - TransAlta) and D. Doram (Environmental Planner-TransAlta).

A special acknowledgement is given to those local landholders who chose to support this project.

REFERENCES

Agriculture Canada. 1981. Research Highlights: Grass Species for Hay and Pasture. Canadian Agricultural Research Station, Melfort, Saskatchewan.

Ahmed, J., C.D. Bonham and W.A. Laycock. 1983. Comparison of Techniques Used for Adjusting Biomass Estimates by Double Sampling. Journal of Range Management, Vol. 36, No. 2, pp. 217-221.

Bjorge, M. 1976. Pasture and Range Management for Alberta. Alberta Agriculture Agrifax. Agdex #134 / 14-6.

Campbell, J.B. and R.W. Lodge. 1955. Sturdy Cage for Range and Pasture Studies. J. Range Management, Vol. 8, 128 p.

Cooke, D.A. 1969. Estimating Herbage Yield from Simulated Grazing Trials. In: J.B. Campbell (ed.) Experimental Methods for Evaluating Herbage. Canada Dept. of Agriculture, Ottawa. Publication #1315:223 p.

Cowlishaw, S.J. 1951. The Effect of Sampling Cages on the Yields of Herbage. J. British Grassland Society, Vol. 15, pp. 179-182.

Deshmukh, I.K. and M.N. Baig. 1983. The Significance of Grass Mortality in the Estimation of Primary Production in African Grasslands. African J. Ecology, Vol. 21, pp. 19-23.

Freese, F. 1967. Elementary Statistical Methods for Forestors. U.S. Dept. of Agriculture. Agruculture Handbook No. 317:87 p.

Green, J.D., H.J. Langer and T.E. Williams. 1952. Sources and Magnitudes of Experimental Errors in Grazing Trials. Proc. 6th International Grassland Congr., Vol. 6, pp. 1374-1379.

Hofmann, L., R.E. Ries and R.J. Lorenz. 1981. Livestock and Vegetative Performance on Reclaimed and Non-mined Rangeland in North Dakota. J. Soil and Water Conservation, Vol. 36, No. 1, pp. 41-44.

Kondra, Z. 1983. Personal Communication. Professor of Agriculture, University of Alberta, Edmonton. Conversation documented in 15 November 1983 memo from T.A. Oddie (Monenco Limited) to D. Doram (TransAlta Utilities Corporation).

Linehan, P.A. 1952. Use of Cage and Mower-Strip Methods for Measuring Forage Consumed by Grazing Animals. Proc. 6th International Grassland Congr., Vol. 6, 1328-1333.

Little, T.M. and F.J. Hills. 1978. Agricultural Experimentation: Design and Analysis. John Wiley and Sons, Inc.

Lopitinsky, K. 1983. Personal Communication. Foratge Specialist, Alberta Agriculture, Barrhead. Conversation documented in 23 November 1983 memo from S.W. Behie (Monenco Limited) to J.B. Railton (TransAlta Utilities Corporation.

McKeague, J.A. 1978. Manual on Soil Sampling and Methods of Analysis. Soil Research Institute, Ottawa. 217 pp.

Monenco Limited. 1982a. Highvale Productivity Monitoring Program 1981. Prepared for TransAlta Utilities Corporation, Calgary.

Monenco Limited. 1983b. Highvale Reclamation Productivity Plots, 1982 - Pasture Sites. Prepared for TransAlta Utilities Corporation, Calgary.

Monenco Limited. 1983c. Whitewood Pre-Mine Productivity Monitoring Program, 1983. Prepared for TransAlta Utilities Corporation, Calgary.

Monenco Limited. 1984. Keephills Productivity Monitoring, 1983. Prepared for TransAlta Utilities Corporation, Calgary.

Montreal Engineering Company, Limited. 1979a. Areal Extent of Canada Land Inventory Classes for the Highvale and Whitewood Mines. Prepared for Calgary Power Ltd., Calgary.

Montreal Engineering Company, Limited. 1979b. Keephills Project Environmental Baseline Program, 1977-1978. Prepared for Calgary Power Ltd., Calgary.

Mott, G.O., H.L. Lucas, W.K. Kennedy, J.T. Reid, M.L. Peterson and D.E. McCloud (eds.). 1962. Pasture and Range Research Techniques. Cornell University Press, Ithaca, N.Y.

Mueggler, W.F. 1976. Number of Plots Required for Measuring Productivity on Mountain Grasslands in Montana. U.S.D.A. Forest Service Research Note INT-207. Logan, Utah.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons.

Nevens, W.B. and A.F. Kuhlman. 1935. A Method of Harvesting Samples of Pasture Forage, J. Dairy Science, Vol. 18, pp. 793-794.

Payandeh, B. and D.W. Beilhartz. 1979. Sample Size Estimation Made Easy. Canadian Forest Service, Dept. of Environment. Publ. ISSN 0704-7797.

Pitt, L.D. and H.F. Heady. 1979. Effects of Grazing Intensity on Annual Vegetation. J. Range Management, Vol. 32(2), pp. 109-114.

TransAlta Utilities Corporation. 1983. Annual Report Whitewood Mine, March 1983.

Van Dyne, G.M., W.G. Vogel and H.G. Fisser. 1963. Influence of Small Plot Size and Shape on Range Herbage Production Estimates. Ecology, Vol. 44, No. 4, pp. 746-759.

Waddington, J. 1983. Personal Communication. Forage Crop Specialist, Canadian Agricultural Research Station, Melfort, Saskatchewan. Conversation documented in 21 November, 1983 memo from T.A. Oddie (Monenco Limited) to D. Doram (TransAlta Utilities Corporation).

Warren, J.A. and I. Mendez. 1982. Methods of Estimating Background Variation in Field Experiments. Agronomy Journal, Vol. 74, pp. 1004-1009.

Webster, R. 1979. Quantitative and Numerical Methods in Soil Classification and Survey. Clarendon Press, Oxford.

Williams, S. 1951. Microenvironment in Relation to Experimental Techniques. J. British Grassland Society, Vol. 6, pp. 207-217.

AN AGRICULTURAL CAPABILITY RATING SYSTEM FOR RECONSTRUCTED SOILS

Terry M. Macyk, ALBERTA RESEARCH COUNCIL

ABSTRACT

This paper provides the rationale and a system for assessing the agricultural capability of reconstructed soils. The concept of capability rather than productivity is used in formulating comparisons between pre- and post-disturbance situations. The system developed parallels the Canada Land Inventory soil capability for agriculture rating system which is presently used to rate soil capability in Alberta. Seven classes and a number of subclasses based on climate, soil and landscape characteristics characterize the system. The degree of climatic limitation is used to establish the base level or starting point in developing and applying the reconstructed soil capability rating system. Other criteria include topography, absence or presence/thickness of topsoil, texture, stoniness, drainage, pH, electrical conductivity, sodium adsorption ratio and erosion.

INTRODUCTION

The pre- and post-mining use of land and land's productive capacity are of vital concern to the landowner, miner and regulatory authority. The concept of or at least the term "productivity" is one that has been used for a number of years when considering the impact of mining on agricultural land. Therefore, it may appear somewhat unusual to be considering the concept of soil capability rather than productivity in this context. Productivity can be described as the measure of output per unit of input as affected by technology and the mix of available resources. It can be suggested that soil productivity is not itself an inherent quality of the soil. Any precise statement about soil productivity must be in terms of a specific kind of soil, a specific kind of crop or combination of crops and a specific set of management practices.

Using productivity as a measure of performance of reclamation does not allow separation of the relative contributions of the land itself and the management inputs. For example, a given level of productivity can be achieved from either good land with minimal management input or poorer land with greater management input.

Capability for agriculture was chosen as the basis for evaluating the product of reclamation rather than productivity because capability considers intrinsic properties of the landscape.

MATERIALS AND METHODS

Developing the System

The basis for developing a capability rating system for reconstructed soils is based largely upon evaluating various soil parameters or properties of reconstructed soils and comparing the results to similar parameters or properties of unmined soils. This allows one to attempt to predict how the reconstructed soils will respond in terms of use.

Any system that is developed must have a "common thread" with a system that is utilized to rate the capability of natural or unmined soils so that meaningful concepts can be developed and relevant comparisons made.

A system that is presently used to rate soil capability in Alberta is the Canada Land Inventory (CLI) soil capability for agriculture rating system (Canada Land Inventory 1965). The system that is proposed for reconstructed soils essentially parallels the CLI system.

The CLI soil capability for agriculture rating system is an interpretive grouping that can be made from soil survey information wherein mineral soils are grouped into seven classes according to their potential and limitations for agricultural use. The first three classes are capable of sustained production of common cultivated crops, the fourth class is considered marginal, the fifth is capable for use in terms of permanent pasture and hay, the sixth is capable of use for native grazing, and the seventh class has no capability or potential for agricultural use. Therefore, if there is to be any thread of continuity between the existing CLI which is suitable for assessing suitability for a given use prior to disturbance then the system or component classes associated with reconstructed soils must reflect respectively similar capability. For example, a CLI Class 1 and a Reconstructed Class 1 should reflect similar capability.

It must be stressed that the CLI rating system is based on soil survey data which is a reflection of relatively stable soils that are generally not undergoing major change in a short time frame. In contrast to this, the data obtained in characterizing reconstructed soils represents a point source in time for any given parameter. Some of these parameters are likely to change some more rapidly than others. Therefore, when a particular rating is applied it is done so based on the properties of the reconstructed soils determined or assumed at a specific time.

It is of paramount importance that all concerned users understand and accept the concept that change is likely to, and certainly will occur, in these reconstructed soils and the appropriate capability rating associated therewith may also change. Also, the capability system and therefore any particular rating assigned is based on existing conditions and not on what the conditions are perceived or predicted to be some time hence. Further research that involves the assessment or quantification of change in reconstructed soils will allow for improvement of the proposed rating scheme and perhaps allow it to be somewhat predictive.

The system is applicable to all mines (disturbances) in the plains region or in any region for that matter in the context of suitability for agricultural crops. This is indeed a "stand alone" system which is not based on pre-mining capability of a particular site. However, it can be suggested that if pre-mining capability is relatively low or poor then it is likely that post-mining capability will also be relatively low. Some exceptions to this will undoubtedly occur. For example, if capability prior to disturbance is low primarily because of topographic or drainage limitations then there is a strong possibility that resultant post-mining topography and drainage will result in a better or higher rating.

Adapting the CLI System

The CLI system of rating soils is based upon climate, landscape and soil factors. It follows therefore, that reconstructed soils should be rated on the basis of similar factors. The description of class and subclass as defined by CLI (Brocke 1977) follow.

The class indicates the general suitability of the soils for agricultural use.

Soil Capability Classes

Class 1 - these soils have no significant limitations to use for crops.

Class 2 - these soils have moderate limitations that restrict the range of crops or require moderate conservation practices.

Class 3 - these soils have moderately severe limitations that restrict the range of crops or require special conservation practices.

Class 4 - these soils have severe limitations that restrict the range of crops that can be grown or require special conservation practices to overcome or both.

Class 5 - these soils have very severe limitations that restrict their capability to producing perennial forage crops and improvement practices are feasible.

Class 6 - these soils are capable only of producing perennial forage crops and improvement practices are not feasible.

Class 7 - these soils or land types have no capability for arable culture or permanent pasture.

It must be emphasized that soils with a capability class are similar only with respect to the degree or intensity of limitation and not the kind of limitation. Each class includes many different kinds of soils and many of the soils within any one class may require different management practices.

Soil Capability Subclasses

The subclass is a grouping of soils with the same kind of limitation. It provides information on the kind of conservation problem or limitation. When used together, the class and subclass provide information about the degree and kind of limitation. Fourteen different kinds of limitations are recognized as a result of adverse climate, soil, or landscape characteristics. The limiting effects of the climate are considered first since they affect the initial capability class or degree of limitation on a broad subregional basis. Next the soil and landscape limitations are considered. The subclass limitations are as follows:

Climatic Limitations - expressed on the basis of adverse sub-regional climate where there are no other significant limitations.

Subclass A	- moisture deficiency due to insufficient precipitation.
Subclass B	- heat deficiency expressed in terms of length of the growing season and cumulative degree days over 42°F.
Soil Limitations	- caused by unfavourable inherent soil characteristics.
Subclass D	- undesirable soil structure and/or slow permeability
Subclass F	- low inherent fertility status.
Subclass M	- low available moisture holding capacity.
Subclass N	- excessive soil salinity.
Subclass S	- unfavourable soil characteristics; used in a collective sense where two or more of the above are present and/or in addition to some other limitation

Landscape Limitations

Subclass E	- erosion damage
Subclass I	- inundation
Subclass P	- excessive stoniness
Subclass R	- shallowness to consolidated bedrock
Subclass T	- adverse topography; both steepness and pattern
Subclass W	- excessive moisture
Subclass X	- cumulative effect of two or more of the above which singly are not severe enough to affect the rating.

Application of the existing CLI system requires the ability to recognize kind of limitation and evaluate the degree or intensity of limitation. It should be noted that there is a lack of specificity associated with the system, and that in many instances subjective evaluations must be made. The system outlines criteria for 14 kinds of limitations, some defined more quantitatively than others. For example, climate is based on precipitation, frost-free period, etc. which is defined to some extent, whereas fertility is generally based on parent material type.

As is done in the CLI system, the degree of climatic limitation is used to establish the base level or starting point in developing and applying the reconstructed soil capability rating system. The logic, simply stated, is that the climate which applies for the pre-disturbance also applies for the post-disturbance situation. The primary climatic factors include the amount and distribution of precipitation, the length of the growing season and frost-free period, and the quantity of heat units available for plant growth. The definition of the climatic classes and the criteria used to characterize these are as follows:

Class	Description	Precipitation	Frost-free Period	Degree days above 42° F
1	Sufficent precipitation and length of growing season to adequately mature wheat	40 to 45 cm (16 to 18")	90 days	2200
2	Moderate climatic limitations due either to a lack of precipitation or a shortened growing season or both.	adequate only 50% of the time	75-90 days	1900-2200
3	Moderately severe limitation due to a lack of precipitation or shortened growing season or both.	30cm (12") or less	60-75 days	1750-1900
5	Very severe limitations due to a very short growing season.		60 days	1750

It should be emphasized that the above is a general guide that was originally developed to characterize climate over relatively large areas. Utilizing this general guide to climatic characteristics the initial or base level capability of an area can be established. For example in Climate Area 1, the highest capability rating would be Class 1 with favourable soils and landscape conditions. Class 1 represents the starting point and any area within Climate Area 1 with adverse soil and/or landscape characteristics is downgraded accordingly. Similarly, in Climatic Area 3, the highest capability rating that could be assigned is Class 3 even though there are not limitations relative to soil and landscape characteristics.

After establishing the base level capability of an area as determined by climate, the next step is to evaluate the properties of the reconstructed soils and the landscape which affect agricultural use. Assessment of topographic limitation includes evaluation of the hazards imparted to cultivation by the degree of slope as well as those due to irregularity of field patterns and lack of soil uniformity as a result of complex landform patterns. This is a limiting factor especially in those areas where no spoil levelling has occurred and to a lesser extent limiting in those areas where partial levelling was undertaken. In the level and gently undulating areas a limitation due to pattern may result from the occurrence of small poorly drained areas which are often the result of levelling procedure or differential settlement. These small areas affect the efficiency and effectiveness of cultivation, harvesting procedures, etc. The criteria used for evaluating topographic limitations for CLI can be utilized in this system and are as follows:-

Slope Class and Percentage	Climatic Area	Degree of Limitation Simple Slopes	(Capability Class) Complex Slopes
Aa and Bb* 0 to 2%	1	1	1
	2	2	2
	3	3	3
	5	5	5
Cc 2 to 5%	1	1	2
	2	2	2
	3	3	3
	5	5	5
Dd 5 to 9%	1	2	3
	2	2	3
	3	3	3
	5	5	5
Ee 9 to 15%	1	3 or 4**	4
	2	3 or 4**	4
	3	4	4
	5	5	5
Ff 15 to 30%	1	5	5
	2	5	5
	3	5	5
	5	6	6
Gg and Hh greater than 30%		6-7***	6-7***

* Uppercase letter - simple slopes; lower case letter - complex slopes
** depending on nature of material and susceptibility to erosion
*** depending on natural grazing potential for domestic animals

Additional landscape features or limitations can be broadly defined. Excessive moisture may be the result of poor soil drainage, a high water table, seepage or the collection of runoff from surrounding areas. In reconstructed soil areas poorly drained features are often the direct result of differential settlement. The degree of limitation is dependent on the duration of the period that these soils remain wet as it affects the timing of cultivation, seeding and harvest.

The CLI system does not formally define the soil factors or limitations to the extent that topography and climate are defined. The approach adopted in developing criteria relative to determining the suitability or limitation of various soil properties was to consider general guidelines already established (Agriculture Canada 1978, Schafer 1979) and to review the characteristics of undisturbed soils that have specific class and subclass designations.

The following discussion describes the subclass limitations as defined by CLI along with remarks pertinent to applicability to reconstructed soils.

Undesirable soil structure and/or low permeability is a limitation for some of the reconstructed soils. In terms of undisturbed soils, this limitation is most commonly utilized for soils prone to crusting which tends to inhibit seedling emergence and may restrict soil aeration. Similarly the illuvial horizons or subsoil of some soils (generally fine textured) also present structural limitations that are restrictive to internal drainage and root penetration. The reconstruction process alters "normal" or pedologically developed structure. The effects of this alteration vary depending upon the soils involved. In terms of orthic soils, the resultant effect is likely to be negative or a diminution of the pre-disturbance characteristics. On the other hand, Solonetzic soils and others characterized by a dense subsoil are likely improved by the reconstruction process. Reconstructed soils that have not been topsoiled are certainly prone to crusting which tends to inhibit seedling emergence. Research conducted by other investigators within the Plains Hydrology and Reclamation Project suggests that infiltration is not necessarily restricted in reconstructed soils (A. Howard, personal communication).

Low inherent fertility status is a limitation that has been applied to Alberta soils on a very limited basis. This limitation is difficult to assess without laboratory data to evaluate fertility status and generally the application of this subclass has been confined to soils developed on very sandy parent materials. In terms of reconstructed soils, those areas where topsoil was applied likely will not have any major deficiencies. In those areas where topsoil was not applied the soils are likely to show deficiencies, however, other subclasses or factors are likely to become limiting before fertility. Furthermore, nutrient deficiencies are relatively easily corrected.

Low available moisture holding capacity is generally associated with sandy soils. This limitation would likely be applicable to areas of reconstructed soils that are characterized by sandy or coarse textured materials.

The excessive soil salinity limitation applies to soils in which the content of soluble salts is sufficient to adversely affect crop growth or to restrict the range of crops that can be grown (salt tolerance). This subclass is frequently used in combination with the landscape limitation for excessive wetness, and in areas of Solonetzic soils where the salts occur very near the surface. This subclass has also been used in combination with the undesirable soil structure and/or low permeability limitation. In terms of reconstructed soils some quantification of levels of salinity is presented in order that the limitation can be appropriately assessed or applied. This was done on the basis of reviewing the literature and assessing the salinity and sodicity levels of undisturbed soils to which the limitation has been applied.

The erosion damage limitation has been applied in evaluating soils where actual damage by erosion (wind or water) has resulted in a limitation to agricultural use. Damage is assessed on both the restriction to the range of crops that can be grown, and the mechanical difficulties presented to farming. Presently erosion does not appear to be a significant problem in the areas of reconstructed soils except for the unlevelled spoil piles. The steeply sloping areas in existence have been relatively successfully revegetated. If these areas were not revegetated there is a strong possibility of severe erosion occurring. However, these areas represent to a large extent, closed systems meaning that material moving down any of the slopes is trapped or contained within the "between pile" depressions.

The inundation limitation has been applied to areas subject to inundation by lakes or streams but not to depressional areas subject to ponding. This limitation is not likely to be a major concern in areas of reconstructed soils.

The excessive stoniness limitation has been applied to soils that are sufficiently stony so as to hinder agricultural activities. Soils with surface stoniness ratings of S3, S4 and S5 as defined in the Canadian System of Soil Classification (Canada Soil Survey Committee 1978) have limitations to agricultural use. In terms of reconstructed soils, this subclass would rarely apply as the dominant limitation since stone removal is one of the procedures employed in preparing the landscape for cropping.

The shallowness to consolidated bedrock limitation applies in areas where consolidated bedrock restricts the depth of the rooting zone. This limitation does not often apply within the agricultural areas, however the concern associated with reconstructed soils relates to the presence of an adequate root zone layer. An adequate root zone could be defined as a layer approximately 1.5 m thick which does not have restrictive zones or layers characterized by high bulk densities. One concern that surfaces relative to a similar problem is that of the "traffic pan" which occurs in reconstructed soils. The "traffic pan" is a layer which occurs approximately in the 25 to 75 cm depth range and where bulk density is greater than that of the material above or below this "layer".

Field observations indicate that ripping does not have an appreciable effect on the density in the traffic pan zone. The effects of the traffic pan are diminished rapidly (2 or 3 years) by freeze-thaw processes and cropping. The traffic pan does not hinder infiltration/percolation because there are adequate macropores present to allow for the orderly movement of water through and away from this zone.

RESULTS AND DISCUSSION

Criteria for Placing Reconstructed Soils into Capability Classes

The soil and soil/landscape limitations defined as part of the CLI system along with their implications for reconstructed soils have been defined. Suitability rating tables that provide good, fair and poor ratings relative to various physical and chemical properties already exist and are provided in a number of publications (Alberta Soils Advisory Committee 1981, Schafer 1979).

Table 1 presents criteria for placing reconstructed soils into soil capability classes for dryland agricultural uses. Included along with the soil parameters are the topography and climate considerations. To determine capability class the top one metre of the reconstructed soil is evaluated on the basis of the parameters included in the table. One metre was chosen in part because the literature indicates that the major portion of plant roots occur in the upper 25 to 60 cm of soil (Russell 1973, Wilhelm et al. 1982). Annual crops such as cereals do not grow actively in the soil long enough for them to develop a really deep root system and in temperate countries rooting does not normally exceed 1 to 1.5 m (Russell 1973). Furthermore, it is generally the top one metre of unmined soils that is considered in developing CLI ratings.

The properties of the top metre of reconstructed soil are considered as one unit. For example, to determine the E.C. value that is applied against the rating table one would calculate a mean value of the results obtained for various samples obtained within the one metre depth. The same approach is taken to consider pH, texture, and SAR in terms of developing or determining ratings. There is the concern that an unusually high or unusually low value will distort the overall mean. In these instances it is up to the rater's discretion whether or not these values are considered in developing mean values and thereby the ultimate rating of suitability or limitation of a specific parameter.

Table 1. Criteria for Placing Reconstructed Soils into Capability Classes for Dryland Agricultural Uses

CLASS	CLIMATE (CLASS)	TOPOGRAPHY (SLOPE %)	TOPSOIL[1] THICKNESS (cm)	SOIL TEXTURE (upper 1 metre)	STONINESS[2] (CLASS)	DRAINAGE[3] CLASS	REACTION (pH)	E.C. (mS/cm)	SAR	EROSION[4]
R1	1	0-2	≥15	L,VFSL	S0-S1	MW-W	6.0-7.5	<2	<4	W1
R2	2	2-5	5-15	FSL,SCL, SiL	S0-S1	MW-W	5.5-6.0 7.5-8.0	2-4	4-8	W1
R3	3	5-9	0^{+}-5	SC,CL	S2	I	5.0-5.5 8.0-8.5	2-4	8-12	W2
R4	3	9-15	0	SiCL	S3	I,R	8.5-9.0	4-8	12-20	W2
R5	5	15-30	0	LS,SiC,C	S4	P,VR	8.5-9.0	4-8	12-20	W3
R6		30-60		S,HC	S5	VP	4.5-5.0	8-12	20-50	W4
R7		>60		any		Water	<4.5, >9.0	>12	>50	

1 Topsoil Thickness - Amount of Ah (Ap) organo-mineral material replaced on surface.

2 Stoniness Class - S0 = Nonstony, S1 = Slightly stony, S2 = Moderately stony, S3 = Very stony, S4 = Exceedingly stony, S5 = Excessively stony (Further definition of classes provided in CanSIS Manual for describing soils in the field (1982)).

3 Drainage Class - VR = Very rapid, R = Rapid, W = Well, MW = Moderately well, I = Imperfect, P = Poor, VP = Very poor

4 Erosion - W1 = Slightly eroded, W2 = Moderately eroded, W3 = Severely eroded, W4 = Gullied (Further definition of classes provided in CanSIS Manual for describing soils in the field (1982)).

Note: 1) Chemical properties in the 0-100 cm control section are considered in applying rating.

2) A combination of more than 2 limiting factors will drop soil by at least one capability class.

A better approach might have allowed for the splitting of the one metre into two units whereby the upper 40 to 50 cm are considered and weighed more heavily than the lower 50 cm in developing a capability rating. This would undoubtedly result in a relatively complex system that is perhaps not warranted at this stage.

The proposed system recognizes the presence or absence of topsoil and some considerations pertinent to depth thereof. Topsoil refers to the organo-mineral A horizon type of material. It can be argued that in some areas topsoil cannot be replaced because it does not occur in the pre-disturbance setting. An example might be areas characterized dominantly by Luvisolic soils. A reconstructed soil in this context would likely be rated a Class R3 or R4 on the basis of climate and other characteristics rather than a lack of topsoil or the presence of poor quality topsoil.

One of the properties that is not considered in the rating scheme relates to the "structure" or relative density of the reconstructed soil. Existing methods of determining bulk density are not particularly useful for characterizing reconstructed soils. The twin probe method is appropriate but it can only be practically utilized in a limited fashion because of the nature of the equipment installations required.

It is apparent that the chemical properties of reconstructed soils are addressed to a greater extent than physical properties and this is largely due to existing knowledge and measurement capabilities. Further research and the development of appropriate equipment will positively impact the situation.

Development of Reconstructed Soil Ratings

Capability ratings are formulated on the basis of relating the reconstructed soil properties to the criteria presented in Table 1.

The class indicates the general suitability of the reconstructed soils for agricultural use. Class symbol is preceded by "R" to designate reconstructed.

Reconstructed Soil Capability Classes

Class R1 - these soils have no significant limitations to use for crops.

Class R2 - these soils have moderate limitations that restrict the range of crops or require moderate conservation practices.

Class R3 - these soils have moderately severe limitations that restrict the range of crops or require special conservation practices.

Class R4 - these soils have severe limitations that restrict the range of crops that can be grown or require special conservation practices to overcome or both.

Class R5 - these soils have very severe limitations that restrict their capability to producing perennial forage crops and improvement practices are feasible.

Class R6 - these soils are capable only of producing perennial forage crops and improvement practices are not feasible.

Class R7 - these soils or land types have no capability for arable culture or permanent pasture.

Reconstructed Soil Capability Subclasses

The subclass represents a grouping of soils with the same kind of limitation. The criteria associated with each of the subclasses in relation to class are provided in Table 1. The symbology associated with the subclasses designated follows:

Topsoil (Absence)	- A
Climate	- C
Erosion	- E
Reaction (pH)	- H
Soil Texture	- K
Salinity (E.C.)	- N

Sodicity (SAR)	-	Q
Stoniness	-	P
Topography and Field Pattern	-	T
Drainage	-	W
Adverse Soil Characteristics (cumulative effect)	-	S

Applying The Reconstructed Soil Capability Rating System

It was noted previously that there is an element of subjectiveness and to an extent a certain lack of specificity relative to the "definitions" associated with the CLI rating system. Furthermore, there is a certain element of subjectiveness associated with the designation of ratings for specific parcels of land.

In terms of the reconstructed soil rating system the class and subclass criteria are defined more fully but there is still an element of subjectiveness involved in developing the final rating designation for a specific parcel of land. The most likely time for confusion occurs when a combination of 2 or more limiting factors occur. A "rule of thumb" that can be applied suggests that a combination of 2 limiting factors does not drop capability by one class. A combination of 3 limiting factors will drop rating by one class or more.

Various scoring techniques were attempted to resolve the problem associated with the element of subjectiveness, however they did not prove entirely workable or represent an improvement over the proposed technique.

Final ratings for the reconstructed soil areas designated at each of the mines are presented in Table 2. Examples are provided to demonstrate how the system should be utilized.

Example 1: The field characterization data and Table 1 provide the following summary:

Climate	-	Class 1
Topography	-	Class 1
Topsoil Depth	-	Class 1

Texture	-	Class 1
Stoniness	-	Class 1
Drainage	-	Class 1
Reaction (pH)	-	Class 1
Salinity	-	Class 2
Sodicity	-	Class 1
Erosion	-	Class 1

Rating = R2N

Because salinity is the most limiting factor and the criteria fit Class 2 the rating is Class R2 with the N (salinity) limitation.

Example 2: The field characterization data and Table 1 provide the following summary:

Climate	-	Class 1
Topography	-	Class 1
Topsoil Depth	-	Class 1
Texture	-	Class 2
Stoniness	-	Class 1
Drainage	-	Class 1
Reaction (pH)	-	Class 2
Salinity	-	Class 2
Sodicity	-	Class 3
Erosion	-	Class 1

Rating = R3Q

Because sodicity is the most limiting factor and the criteria fit Class 3 the rating is Class R3 with the Q (sodicity) limitation.

CONCLUSIONS

The capability system developed allows for an ordered ranking of relative capability of reconstructed soil areas, however the ratings do not provide for quantification or allow for the detailed assessment of production capacities and the effects of different management techniques. This can only be accomplished through the measurement of yield.

REFERENCES

Agriculture Canada. 1978. Soil quality criteria for agriculture. Prepared by sub-committee of Alberta Soils Advisory Committee.

Alberta Soils Advisory Committee. 1981. Proposed soil quality criteria in relation to disturbance and reclamation.

Brocke, L.K. 1977. Soil capability for agriculture in Alberta. Report prepared for Alberta Environment. 24 pp.

Canada Land Inventory. 1965. Soil Capability Classification for Agriculture. The Canada Land Inventory Report No. 2. Environment Canada, Ottawa. 16 pp.

Canada Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification, Can. Dept. Agric. Publ. 1646. Supply and Services Canada, Ottawa, Ont. 164 pp.

Canada Soil Information System (CanSIS). 1982. Manual for describing soils in the field. Edited by J.H. Day, Land Resource Research Institute, Ottawa, Ontario.

Macyk, T.M. 1984. Characterization and variability of reconstructed soils. Draft report prepared for Research Management Division, Alberta Environment.

Peters, T.W. and W.W. Pettapiece. 1981. Crop yields in Alberta. Preliminary relationships to soil capability for agriculture and soil type. Alberta Institute of Pedology Contribution No. M-81-1.

Russell, E.N. 1973. Soil Conditions and Plant Growth. 10th edition, Longman Group Limited, New York. 849 pp.

Schafer, W.M. 1982. Changes in land capability class resulting from mining in the northern great plains. In Symposium on Surface Coal

Mining and Reclamation in the Northern Great Plains, March, 1982.

Schafer, W.M. 1979. Guides for estimating cover-soil quality and mine soil capability for use in coal stripmine reclamation in the Western United States. Reclamation Review Vol. 2:67-74.

Wilhelm, L.N., Mielke, L.N. and C.R. Fenster. Root development of winter wheat as related to tillage practice in western Nebraska. Agron. J. 74: 85-88.

RECLAMATION OF GRAVEL PITS - PROVINCE OF ALBERTA

N.J. HERTZ

PAST PRESIDENT, ALBERTA SAND AND GRAVEL PRODUCERS ASSOCIATION

In the province of Alberta the Department of Environment is responsible for the development and reclamation of gravel pits under the Land Surface Conservation and Reclamation Act of 1973 and the Land Conservation Regulations as filed Alberta Regulation 125-75. There have been various amendments to the Act but generally the intent is the same.

Under the Act, the regulations are specific but still allow the applicant to detail the contents of an application. It is the responsibility of the applicant to design the method of extraction as well as provide for reclamation that will, in the eyes of the Department of Environment, return the land to its best use.

The sand and gravel industry, prior to the introduction of reclamation standards and policies, certainly did not have a very good public image in the province of Alberta. One only needs to travel in the province to see the many scars that were left prior to the enactment of legislation. The unreclaimed pits are still a serious problem which has to be faced by the Municipal Districts, Counties, and/or the Provincial Government. Many of the operators who were responsible for the untidy operations are no longer in business and therefore the pits remain looking like a bombed-out area.

It is interesting to note that the sand and gravel industry in the province formed a closely knit association and approached the provincial government with a view of having some type of standard introduced in order to upgrade the public image of the sand and gravel industry.

At that time, the Department of Environment responded and drafted regulations which were reviewed both by government and industry members and eventually were accepted by the government and which still form the basic concepts in the reclamation regulations.

In the last decade we have had increasing concerns regarding the land use after the conclusion of the actual sand and gravel operations.

Alberta Environment defines reclamation as including all desirable and practical methods for:

a) designing and conducting a surface disturbance in a manner that minimizes the effect of the disturbance and enhances the reclamation potential of the disturbed land;
b) handling surficial material in a manner that ensures a root zone that is conducive to the support of plant growth required for future uses;
c) contouring the surface to minimize hazardous conditions to ensure stability and to protect the surface against wind and water erosion; and
d) that allowed the loss and re-establishment of the ground water aquifers is a major consideration in reclamation technology, present knowledge does not permit specific guidelines other than stating the objective of replenishing the ground water source for beneficial use.

Having said all that, it still leaves us with the problem of having to come up with a plan and a method of operation that will enable us to get the best land use both during and after the sand and gravel operations are complete. In most counties and municipal districts, a sand and gravel operation now requires a development permit. One of the conditions of this development permit normally is that the Department of Environment approve the plan of operation which includes reclamation.

The applicant or the sand and gravel operator is responsible to draw up a set of plans which outline the method of operation, the sequence in which he will operate his deposit, and the contour to which the property will be reclaimed. There are cetain criteria in the regulations which control this type of operation and some of them are:

a) topsoil or blackdirt as it's referred to, is removed and stockpiled separately. We have in some instances just spread it over an area that is being cropped. We just increase the depth of black dirt and in this way, it is simple to control weeds.

b) The next layer, the root zone, which could be anywhere from 12" to 3', is removed and stockpiled separately, and then the clay or whatever sand overburden which overlays the gravel deposit is removed and stockpiled which then exposes the pitrun gravel. Pitrun gravel meaning the gravel in its raw state in the deposit.

The operations of the sand and gravel pit differ immensely in certain parts of the province. In some areas where the overburden, the topsoil and root layer might only be 6", and then you're into the gravel deposit. In other areas of the province, we strip as high as 35 to 40' of overburden to reach the gravel deposit. This, of course, presents a much more serious problem, both in operations and reclamation. In most rural areas, gravel pits are reclaimed to where the land use will be agricultural. However, we now have many gravel pits inside City limits and very close to urban areas and these present various alternatives to the pit owner.

One of the major uses of worked out gravel pits in urban areas has been a sanitary landfill and in Edmonton, in particular, we have the City of Edmonton active sanitary landfill on the site or worked out gravel pits.

There are many end land uses for worked out sand and gravel pits. In most cases, particularly in rural areas, the site will be reclaimed to agricultural use. The final land use will revert back to the use prior to the aggregate removal operation.

In urban areas such as the City of Emdonton, which is one I'm most familiar with, there are other land uses.

With proper planning, a gravel pit can have multiple uses. With the correct zoning, the land can have three economical uses:

1) as a sand and gravel operation;
2) as a sanitary land fill; and
3) as a park/recreation facility.

The City of Edmonton uses approximatly 20-25 acres of land per year for sanitary land fills. This doesn't sound like a lot of land in one year but taken over a twenty year period, we're looking at 400 acres. This area represents more than on depleted gravel pit.

Some of the same cost savings are common to all land uses. Transportation short haul for the gravel operation makes the operation more competitive, similarly, the short haul for waste cuts down the cost to the city. And finally, a park close to the city allows more use of the facilities.

In smaller centres where there is not as large a land requirement for sanitary land fills, the depleted gravel pit can be reclaimed direct to a park. We should also not overlook the fact that depleted gravel pits in urban areas are developed into residential or industrial subdivisions.

The single most important item when planning to open a gravel pit is what will the land use be when the pit is depleted.

PUT IT BACK THE WAY YOU FOUND IT

G. DeSORCY
VICE CHAIRMAN, ALBERTA ENERGY RESOURCES CONSERVATION BOARD

Thank you Mr. Chairman. It's a pleasure for me to address this annual meeting of the Canadian Land Reclamation Association.

Turning now to reclamation, the topic of the day, I, probably like a lot of you, initially learned about reclamation from my parents. My mother would say "you kids leave that room the way you found it", or my father would hand me a shovel and say "put that garden back into shape". However you people, unlike myself, have gone on to develop a special expertise in reclamation. This is evidenced by the impressive list of papers being presented at this meeting.

Not being an expert in the area, I am no going to waste your time attempting to deal with the technical aspects of reclamation. Rather what I am going to do is briefly outline for you the role of the ERCB in reclamation, relay to you our perceptions of the landowners' reactions to reclamation, and suggest a few ways in which all of us might better inform these landowners, and the general public, as to what is being accomplished in the field of reclamation.

ROLE OF THE ERCB

As many of you are aware, the ERCB is a provincial agency which regulates most aspects of energy resource development in Alberta. It does not have a lead role in reclamation. The ultimate responsibility for that important aspect of the energy business rests with Alberta Environment. However, there are two exceptions: The Board does have some direct involvement in that it is represented on two committees which are part of Alberta Environment's Land Conservation and Reclamation Council, specifically the Exploration Review Committee and the Development and Reclamation Review Committee. And secondly, with respect to certain accidental occurrences in energy operations, the Board has first line involvement in reclamation and rehabilitation, with a prime example being the clean-up of oil spills.

In addition there are two other activities of the Board which are very significant. First, because the Board has an approving responsibility with respect to essentially all energy resource developments, and because its legislation requires a hearing process when potentially affected parties object to a development, this means that the Board frequently hears from landowners at public hearings who often raise issues of reclamation, and request that the manner of creating the disturbance be regulated, such as to make the ultimate successful reclamation more easily attainable.

The second activity of importance occurs because the Board has field offices and inspection staff located throughout the province. In this manner it hears from landowners when they have complaints about industry operations or developments, including problems which are related to reclamation.

As a result of these two sources of information, either comments at public hearings or complaints registered at our field offices, the Board has a unique opportunity to hear from landowners.

RECLAMATION ISSUES AS PERCEIVED BY THE ERCB

I have reduced the general comments heard from landowners by the Board and its staff into a list of questions, and conclusions or issues, which seem to represent a consensus position of those landowners that we hear from. In doing so, and in passing them on to you, I have to acknowledge that they are based on reactions from a limited sample of landowners. Nevertheless, it is a large enough sample that I believe the results do have meaning.

The messages that we are hearing and that I want to pass on to you are as follows:

1. An increasing number of landowners are aware of and seem to like the attention being paid to reclamation, particularly, in the project planning stage. But concerns do remain and many landowners appear to be unaware of or unconvinced that lands will be successfully reclaimed.

2. The rural agricultural community has a deep-rooted concern that too much prime land is being taken out of agricultural production or is having its productivity reduced.

3. There are sufficient examples of less than perfect reclamation in the past to provide landowners with an arsenal of reclamation issues with which to oppose proposed projects. This is particularly the case because the agricultural community has become increasingly organized and there is an on-going exchange of information from one region of the province to another.

4. There are some concerns that the agency which approves disturbances is not responsible for the reclamation. Landowners thus contend that insufficient care is being exercised at the approval stage to ensure that reclamation can be accomplished.

5. A number of landowners are concernd that there are hidden chemicals or other pollutants in the soil which may be a long-term problem. A problem that they will be left with after reclamation has been approved and the resource development company has departed.

6. Many landowners feel that they don't receive sufficient compensation to cover the risk of reclamation. They worry that reclamation will not be successful and there will be a long-term negative impact on the soil.

7. The landowners and the general public do not appear to realize how much knowledge and technical expertise exists in regard to reclamation and the rate at which it is being improved. For example, I doubt that many of them know this association exists or that meetings such as this one are held to discuss the highly technical aspects of reclamation.

8. I am pleased to report that an increasing number of landowners are noting and commenting on improvements in lease construction and sump disposal methods and other aspects of land disturbance. The message that these improvements are being made however, is not being widely

distributed. Many opinions being expressed by landowners are not based on what is happening today but rather on problems that occurred in the past.

9. There is confusion among landowners as to which government department is responsible for reclamation. Since the ERCB holds public hearings and investigates complaints, many landowners assume it has final responsibility for reclamation. I expect there are some in the industry itself that are confused as to where government responsibilities lie in this regard.

NECESSARY ACTIONS

Assuming that the matters I have just reviewed to to some extent reflect the consensus of landowners, the next question is what should be done about it. It is necessary to deal with the negative comments of landowners who are being affected by energy developments in such a way that we can ensure that the positive messages we are beginning to hear will become more prevalent in future. Obviously continued development of reclamation tecnology, which you people are so involved in, must continue. Also those interfacing with landowners must treat them in an open, honest and fair way as well as being businesslike. Additionally however, all of us must work to ensure that the landowners know that reclamation is being considered in the project planning stage, that satisfactory reclamation is going to occur, that much research is taking place regarding reclamation and that organizations like this one exist. We in the public sector must take steps to minimize the overlapping of jurisdictions among government departments and to make certain that the landowners and the industry understand which government departments carry specific reclamation responsibilities.

How can we do these things? The most important way in my view is to get out into the rural community and tell the people what is going on in reclamation. This can be done through local fairs and expositions and also by being available to attend meetings of agricultural groups and by making it known that experts are available for that role.

Initiatives should be taken by reclamation groups in industry and government to set up seminars in rural areas. Attendance of opinion leaders from the agricultural communities at conferences such as this one should be encouraged.

It is important to have available brochures or pamphlets describing what is taking place in reclamation and what the various government departments' responsibilities are, but these must be relatively brief and written in down-to-earth language.

I know that all of these things I have mentioned are occurring to some extent now. What I am suggesting is that we should be going further. Reclamation technology is improving steadily. The reclamation work that we see taking place is generally good and it is improving. What we must do is increase efforts to make the landowners and the general public aware of these accomplishments and that the industry and government are serious about reclamation. Whether we like it or not, a message commonly heard on hearings is that the industry and government lack credibility.

Through greater efforts in the areas I've outlined, I believe there will come a day when the landowner can ask "Are you going to put it back the way you found it?" and we will be able to answer "yes, sir", with confidence that all of us will understand what the other means.