

TWO DECADES OF RECLAMATION RESEARCH IN THE
SUBALPINE REGION OF ALBERTA

T.M. Macyk¹, Z.W. Widtman¹ and V. Betts²

¹ Alberta Research Council, Box 8330, Station F, Edmonton, Alberta T6H 5X2; and

² Smoky River Coal Limited, Box 2000, Grande Cache, Alberta, T0E 0Y0

ABSTRACT

The Alberta Research Council has conducted a surface mine reclamation research program in association with the operations of Smoky River Coal Ltd. near Grande Cache, Alberta since 1972. The main objective of this long-term on-going study is to develop and refine methods of establishing and maintaining a vegetative cover that is in harmony with adjacent undisturbed areas. Use of appropriate materials handling techniques including coversoil replacement strategies and selection of suitable plant species combined with good management practices has resulted in the establishment of diverse plant communities that allow for different land use options. The soils reconstructed after mining are generally coarser textured, higher in pH and lower in available nutrients than unmined soils. Plot studies to determine the suitability and adaptability of various agronomic and native grasses and legumes as well as fertilization trials were established and monitored annually. Container and bare root conifer seedlings and cuttings of deciduous species were utilized initially to establish trees and shrubs in the area. Direct seeding has also proven to be a viable method for establishment of trees and shrubs in the area. Long-term monitoring results indicate that desirable agronomic species will thrive and reproduce at this elevation and that native species including trees and shrubs will invade the revegetated areas. Coarse fragment content, distance from nearest upwind seed source and slope were identified as the most significant variables influencing native species invasion of previously revegetated areas. Long-term climate monitoring data support the conclusion that climate is the most limiting factor to reclamation success in the region. Firm conclusions and recommendations regarding appropriate reclamation practices for the region can be drawn from the results of the long-term research effort and monitoring of operational reclamation. The success of reclamation in the study area is measured by the productivity achieved and the presence of and utilization by wildlife.

**Deux décennies de recherche en réhabilitation
dans la région subalpine de l'Alberta**

par

T. M. Macyk, Z. W. Widiman et V. Betts

Depuis 1972, le conseil de recherche de l'Alberta poursuit un programme de recherche en réhabilitation des sites exploités par des mines de surface, en association avec Smoky River Coal Ltd., près de Grande Cache en Alberta. L'objectif principal de cette étude à long terme est de développer et de raffiner les méthodes de recouvrement végétal de sites, qui s'harmoniseraient avec les secteurs adjacents non-perturbés. L'usage de méthodes appropriées, incluant le choix des matériaux, les stratégies de remplacement de la couche superficielle des sols, la sélection d'espèces végétales appropriées, combinée à une bonne pratique de gestion, permettant implantation d'une variété de populations végétales, favorise différentes utilisations du secteur ainsi réaménagé. Les sols réaménagés à la fin des travaux d'exploitation minière sont généralement de texture plus grossière, avec un pH plus élevé et un contenu en éléments nutritifs plus faible que les sols non-perturbés par l'exploitation minière. Des études de secteurs furent effectuées afin de déterminer d'une part, la justesse du choix des différentes espèces d'herbes et légumes agronomiques et indigènes, et d'examiner d'autre part, leur capacité d'adaptation. Des essais de fertilisation furent également effectués et contrôlés une fois l'an. Au début, des pousses de conifères, en contenant ou à racines découvertes, ainsi que des greffes de feuillus furent utilisés pour reboiser le secteur. Des graines furent également directement semées, ce qui s'est révélé être une bonne méthode de reboisement. Le résultat des contrôles, sur une longue période de temps, montre que les espèces agronomiques désirables peuvent croître et se reproduire à cette altitude et que les espèces indigènes, comprenant arbres et arbustes, envahissent les secteurs restaurés. Les variables les plus importantes, influençant l'invasion d'un secteur restauré par les espèces indigènes, sont le contenu du sol en fragments grossiers, la distance de la source de semences en relation avec le facteur de transport éolien et la pente du site. Les données de surveillance climatique à long terme supportent la conclusion que le climat représente le facteur le plus limitatif en ce qui a trait au succès de la réhabilitation. De fortes conclusions et recommandations peuvent, être tirées, concernant la pratique de réhabilitation dans cette région, à partir des résultats de l'effort clé recherche à long terme et des contrôles sur le terrain. Le succès de réhabilitation du secteur à l'étude est mesuré par la productivité observée ainsi que par la présence et l'utilisation du site par la faune sauvage.

INTRODUCTION

The Environmental Research and Engineering Department of the Alberta Research Council has been conducting a reclamation research program in the Grande Cache area on behalf of Smoky River Coal Limited since May 1972. Reclamation research was truly in its infancy in Alberta when this project was undertaken.

The operations of Smoky River Coal Limited (Figure 1) are located in the Rocky Mountain Foothills approximately 150 km north of the town of Jasper. The four major surface mining operations are the No. 8, No. 9, No. 11 and No. 12 Mine areas located adjacent to the Smoky River and Sheep Creek respectively. Elevations range from 1500 to 1800 m and the topography is steeply sloping.

OBJECTIVES

The initial and overall objective of the research project was to determine methods of establishing a long-term vegetative cover that is in harmony with adjacent, undisturbed areas. The subobjectives identified were to:

- a) characterize unmined and reconstructed soils and evaluate their suitability for reclamation purposes;
- b) determine, by field testing, suitable grasses and legumes for establishment of a protective vegetation cover on reclaimed areas to minimize erosion; and
- c) determine by field and laboratory testing, the nutrient requirements for maintaining a viable vegetative cover.

Because this study has been ongoing for a relatively long time new objectives were added as additional needs were identified. It is important to note that the length of record for many experimental activities allowed for the development of more firm conclusions and recommendations for operational reclamation practices. Conclusions drawn and recommendations made were modified as the length of record increased particularly with respect to some issues. The major research activities or topics associated with the project are grouped under the following major headings.

- 1. Soil and spoil materials
 - a) pre- and post-mining soil characterization and quality assessment
 - b) soil management (salvage, replacement)
 - c) soil depth requirements for vegetation establishment
 - d) spoil characterization and quality assessment
- 2. Vegetation establishment and maintenance
 - a) selection and use of appropriate agronomic and native grasses and legumes
 - b) appropriate fertilization practices that allow for stand maintenance and encroachment by native species

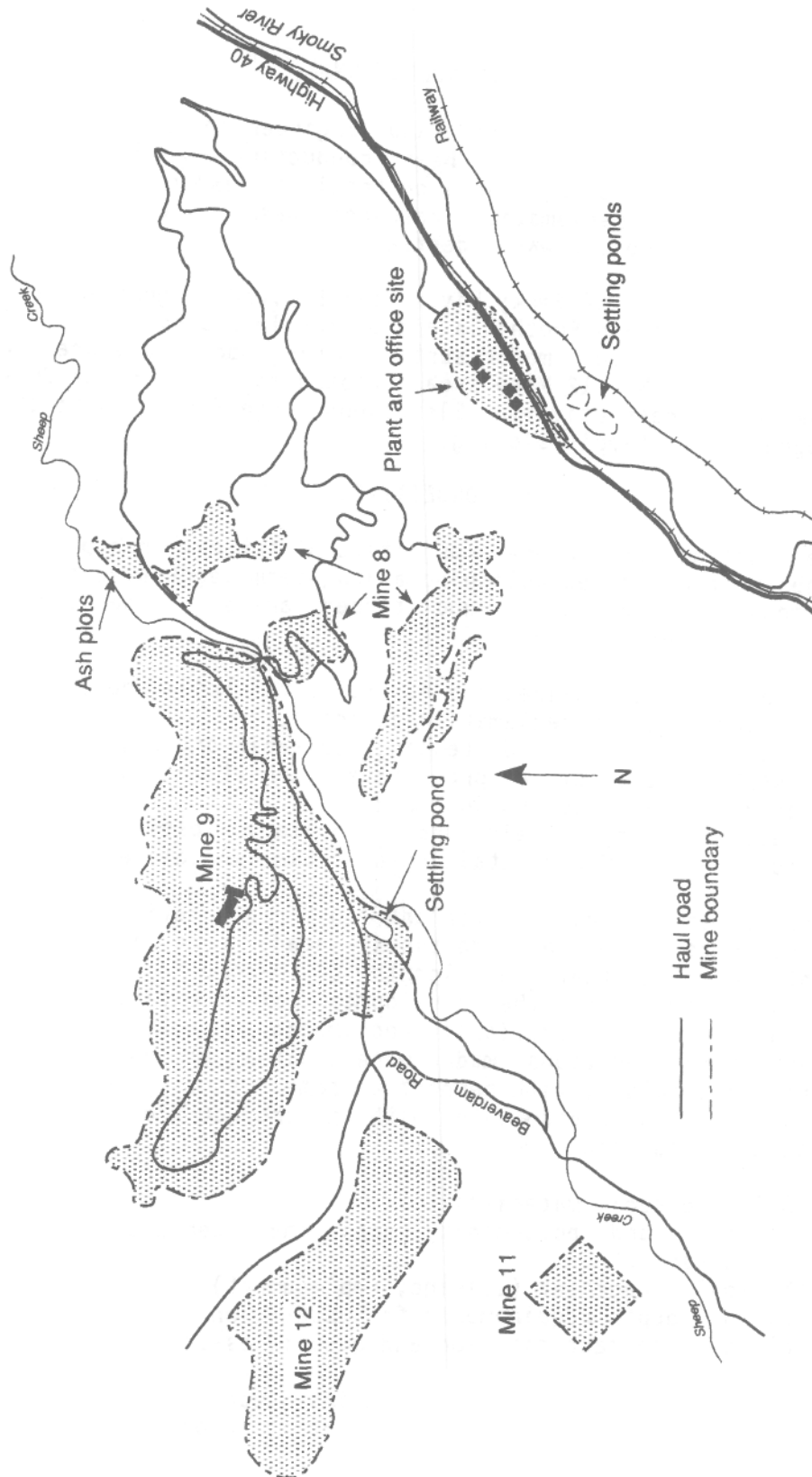


Figure 1. Operations of Smoky River Coal Limited

- c) appropriate seedling stock and planting methods and direct seeding techniques for establishment of trees and shrubs
 - d) evaluation of the factors influencing native species invasion
3. Revegetation of areas affected by fly ash disposal
 4. Detailed climate monitoring
 5. Equipment design for operational reclamation
 6. Technology transfer

MATERIALS AND METHODS

Coal production from surface mining commenced in the area in June, 1971. The research program that included groundwater investigations and emphasized soils and revegetation concerns began in May, 1972.

Unmined Soils

The research associated with "soils" in this project warranted major attention because of the need to provide pertinent baseline information and to deal with the characteristics and behavior of reconstructed soils. A number of discrete projects were undertaken to evaluate the unmined soils occurring in the area and the characterization and monitoring of reconstructed soils was and continues to be an ongoing activity in the overall research program.

First of all, the unmined soils immediately adjacent to the initial disturbance at No. 8 Mine were characterized (Macyk 1972). A soil survey of the No. 9 Mine (Macyk, 1973) prior to mining was completed and in 1981 some preliminary work was undertaken to characterize the soils occurring in the proposed No. 7 Mine area (Macyk, 1981). Soil surveys and soil suitability evaluations were completed for the No. 8 Mine, (Macyk and Widtman, 1985), No. 12 Mine (Macyk and Widtman, 1986) and No. 11 Mine (Macyk and Widtman, 1988b) areas.

The soils were described, mapped and classified according to the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987; Canada Soil Survey Committee, Subcommittee on Soil Classification, 1978). The soils were dominantly Brunisolic and Luvisolic with lesser amounts of Regosolic and Gleysolic soils. The depth of salvageable material overlying bedrock ranged from 10 cm to 1 m.

Soil suitability ratings for each of the soil units identified and mapped were prepared according to soil quality criteria relative to disturbance and reclamation (Alberta Soils Advisory Committee, 1987). In summary, it can be stated that the soils which occur in the area are generally fair to good in terms of suitability for reclamation.

Reconstructed Soils

The soils reconstructed after mining do not duplicate the soils that existed prior to disturbance. Sampling of reconstructed soils occurred throughout the life of the project and results were reported in the respective annual reports. Sampling generally involved collection of the soil topdressing material and underlying spoil or overburden. In addition, the overburden or spoil materials were sampled extensively at No. 9 Mine.

The experimental work conducted throughout the project indicated that reconstructed soils are generally coarser textured, higher in pH, and lower in available nutrients than the unmined soils.

Vegetation Establishment

A specific end land use was not developed at the time that the project was initiated, however, the overall goal was to establish a long-term self sustaining cover that is in harmony with the adjacent undisturbed area. Erosion control was the major initial consideration relative to establishment of a vegetative cover and was to be followed by the re-establishment of wildlife habitat. Current requirements in portions of the disturbed areas include the re-establishment of commercial timber.

The vegetation work was initiated in May 1972 with the establishment of three plot areas, the first of many to be established and monitored during the project to date. During the course of the project some 40 plot areas were established to address specific concerns.

The initial three plot areas that were established included 60 individual 6 m x 9 m plots to determine the suitability of 30 different agronomic grasses and legumes (Macyk, 1972). Fertilizer trials were included to determine the most appropriate fertilizer types and analyses to be used, as well as timing and rate of application.

Early in the study concerns relative to the utilization or re-establishment of native plant cover were raised. The use of native species was argued on the basis that animals prefer them, that less maintenance is required following establishment and that natives are more aesthetically pleasing. However, in 1972 "native" seed was not available on a commercial basis. Therefore, seed from Hairy wildrye (*Elymus innovatus*), lupine (*Lupinus* spp.), Alpine hedysarum (*Hedysarum alpinum*) and loco-weed (*Oxytropis* spp.) was collected in the undisturbed portions of the mine area and subsequently planted in selected locations.

A program to introduce trees and shrubs to the disturbed area was undertaken concurrently with the grass and legume establishment program. This program involved the use of a variety of propagation and planting techniques. Because conifer seedlings suitable for planting above an elevation of 1100 m were unavailable at the time, a cone collection program was undertaken and greenhouse space acquired to produce

lodgepole pine (Pinus contorta var. latifolia), engelmann spruce (Picea engelmannii) and white spruce (Picea glauca). Different types and sizes of containers were utilized to determine which ones were most effective for use in the reconstructed areas and to determine cost-effectiveness. Bare root seedling stock was also utilized.

Willow (Salix spp.) and balsam poplar (Populus balsamifera) cuttings as well as root cuttings of aspen (Populus tremuloides) were rooted in the greenhouse. Willow cuttings were also direct planted. Most of the materials were planted in areas having an established grass and legume cover.

A direct seeding program to establish spruce and pine was undertaken in 1983 to determine whether this procedure could be effective on an operational scale. The program was expanded in subsequent years to include alder (Alnus spp.).

A study to assess the native species re-invasion phenomenon was undertaken as a graduate student thesis project. Data collection for the project involved the use of "mini-transects" originating at "grid points" or intersections on the minesite. A 60-meter interval grid pattern was established with each intersection representing a data collection point.

Climate monitoring began in 1973 with the measurement of precipitation followed by installation of Model TA 51 Biophenometers (Omnicdata International Inc.) to measure growing degree-days and Campbell Scientific CR21 (Campbell Scientific Inc.) units to monitor soil and air temperature. In addition Model 824 Easylogger units (Omnicdata International Inc.) which are 12-channel portable data recorders were installed to measure air temperature, soil temperature, wind speed, wind direction, relative humidity, solar radiation and soil moisture. The parameters are measured at three-minute intervals and a minimum, maximum and mean value recorded on an hourly basis.

RESULTS AND DISCUSSION

Establishment of Agronomic Grasses and Legumes

Most of the agronomics seeded initially became established and continue to thrive with many of the species producing viable seed. Time and annual monitoring of growth allowed for the development of an appreciation of species suitability (desirability), stand composition and fertilizer requirement.

Very few of the grass and legume species utilized could be described as unsuitable for use in reclamation in this region. It was observed that the dominance of specific species and/or varieties was related to aspect and associated moisture conditions as well as the effect of competition.

In the initial years of the study importance was placed on achieving a self-sustaining cover of grass and legume species in the area by the authors and other researchers and observers. This led to

assessing the species on the basis of their performance for long-term survival and to some extent optimizing productivity or total plant cover. 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. Alfalfa has become a very important component of the seed mixtures used in the area and plays a major role in achieving and maintaining a self-sustaining cover.

Work done to evaluate native species re-invasion indicated that the initial cover established does not have to sustain itself indefinitely or be maintained for much more than five years after initial establishment. What is required is the selection and use of species that will provide the initial and necessary erosion control cover while at the same time rejuvenating or getting the reconstructed soil functioning to promote subsequent changes in cover. Therefore, one must consider on a site specific basis whether the most pressing need is a very effective erosion controlling cover or an appropriate nurse crop for the addition of natives early in the overall revegetation scheme or both.

Fertilizer Requirements

The undisturbed and reconstructed soils in the region have very low levels of plant available nutrients. The grasses and legumes seeded initially in the area showed a marked response to the application of fertilizers. During the term of the study a variety of different fertilizer types and analyses including conventional and slow release types were utilized in both the research plots and the operational reclamation areas. The plots established to evaluate the use of fertilizers have been maintained and monitored annually since 1972.

Long-term observations indicate that refertilization is not required annually to maintain the established cover. Results indicated that for the establishment of the initial grass or grass/legume cover fertilizers should be applied at the time of seeding (year 1) and the following year (year 2). Recommendations relative to the appropriate application rates and timing of applications have been developed.

Native Species Invasion

From the early stages of the project field observations indicated that native species were encroaching into the disturbed areas where a grass/legume cover had been established. The non-woody species that were naturally invading included lichens, mosses, lupine, loco-weed, alpine hedysarum and Indian paintbrush (*Castilleja tularensis*). Willow, alder, balsam poplar, spruce, pine, and subalpine fir (*Abies lasiocarpa*) were also found in the area. Initially, the presence of natives was attributed to the germination of seed and sprouting of vegetative material that was present in the replaced soil topdressing. It also became apparent that dispersion of seed by wind and animals also plays a major role in native species invasion.

The assessment of the rate and extent of native species invasion is important for a number of reasons. Although seed for native species is currently more readily available than it was in the past, it would be difficult from a cost standpoint and seed availability perspective to revegetate large areas entirely with natives. Having some knowledge of the extent to which one can depend on invasion is critical in reclamation planning. Invasion increases species diversity, impacts the development of a self-sustaining vegetative cover, and increases the stability of the post-mine ecosystem. Identification and ranking of the factors influencing the invasion by native species will have a bearing on the development of reclamation plans in the future.

Plant counts were undertaken in 5 m x 5 m plots to get an initial indication of the extent of invasion (Macyk and Widtman, 1984). Data from these plots indicated a decrease in native species populations with increasing distance from the undisturbed forest. In 1986 a much more intensive study was undertaken to identify and rank the factors affecting the areal extent and distribution of native species at the No. 8 Mine site (van Zalingen et al., 1988). These factors included distance from undisturbed forest, presence or absence of legumes in seed mixtures utilized, airborne seed dispersal, slope, aspect, dates of seeding and fertilization, and soil characteristics.

A total of 60 nonseeded species, including eight native legumes, were identified on the site. Statistical analyses were undertaken to assess the parameters measured and these parameters or variables were ranked to determine their relative importance.

Overall, distance from the nearest westerly undisturbed area significantly influenced the distribution of native species in the area. With the exception of moss, all native species exhibited a decline in percent cover with increasing distance from the nearest westerly undisturbed area. Ranking of the independent variables indicated that coarse fragment rating was the most important variable contributing to the percent cover of native species. Northwest versus southeast aspect and distance from the nearest westerly undisturbed area ranked second in importance followed by percent cover of alfalfa. Percent slope and soil depth ranked low in terms of importance compared to the above mentioned variables.

Tree and Shrub Establishment

A program to introduce trees and shrubs to the area was undertaken concurrently with the grass and legume establishment program. Utilization of the different propagation and planting techniques resulted in excellent tree and shrub establishment. The results demonstrated that trees and shrubs will thrive when planted in areas having a grass and legume cover. This practice was questioned initially because of an anticipated competition for moisture. It became obvious that the negative aspects of competition for moisture were far outweighed by the protection afforded the seedlings by the grass and legume cover, especially in holding snow in the winter.

Climatic limitations dictate that some form of protection for the young seedlings is critical in this region. During the winter it is not unusual to have the snow cover blown off by strong winds or melted down during periods of warm weather. Subsequent cold spells, especially if accompanied by strong winds can be particularly detrimental to young seedlings. Winds averaging 60 to 70 km/hr for 6 to 8 hours per day are not unusual during the winter months. During the summer, surface and near surface soil temperatures can reach in excess of 45°C to 50°C for several hours on consecutive days (Macyk and Widtman, 1986; Macyk and Widtman, 1991).

Shrub Establishment. The shrubs utilized in the study included alder, willow, buffaloberry (*Shepherdia Canadensis*), arid caragana (*Caragana arborescens*). In 1973, cuttings of alder, buffaloberry and willow were collected at the No. 8 Mine area and rooted in containers in the greenhouse. Caragana was produced by placing seed in the containers. Cuttings of willow were also collected in early May and direct planted without any treatment or pre-rooting.

Five years after planting 65% of the willow cuttings, 80% of the alder and 60% of the caragana had survived and continue to thrive. Many of the willow that were planted in 1973 had achieved heights in excess of 3 m by 1987 and are continually clipped by browsing wildlife. The direct planted willow cuttings had a survival rate of 40% after five years.

Preliminary results of direct seeding trials indicate that alder can be readily produced by this method in the area (Macyk and Widtman, 1991). Furthermore, this conclusion can be supported on the basis of the number of alder plants that are becoming established by natural means.

Conifer establishment. The program to establish conifer species in the No. 8 Mine areas was initiated in 1972. Annual reports completed by the authors and conference papers (Macyk and Widtman, 1987b) document some of the specific studies and respective results associated with planting methods, survival rates and initial results of the direct seeding trials. For example, the 1984 annual report (Macyk and Widtman, 1984) compared the growth of trees in the reclaimed area with those growing in reforested areas that had previously been logged for pulp industry purposes.

A major program initiated in 1983 to compare the growth of conifers on unmined (natural) and reconstructed soil emphasized a comparison of rooting depth and pattern. In addition 100 conifer seedlings were tagged at each of two sites referred to as Area I and the Highwall Site and in the respective adjacent unmined areas. Figure 2 indicates that the mean annual growth of pine was only marginally better on natural soils than the reconstructed soils over the six-year period. Figure 3 indicates that the mean annual growth of spruce was very similar for both reconstructed and unmined soils.

Direct seeding trials for conifer establishment were undertaken for two major reasons. First of all, investigations relative to seedling

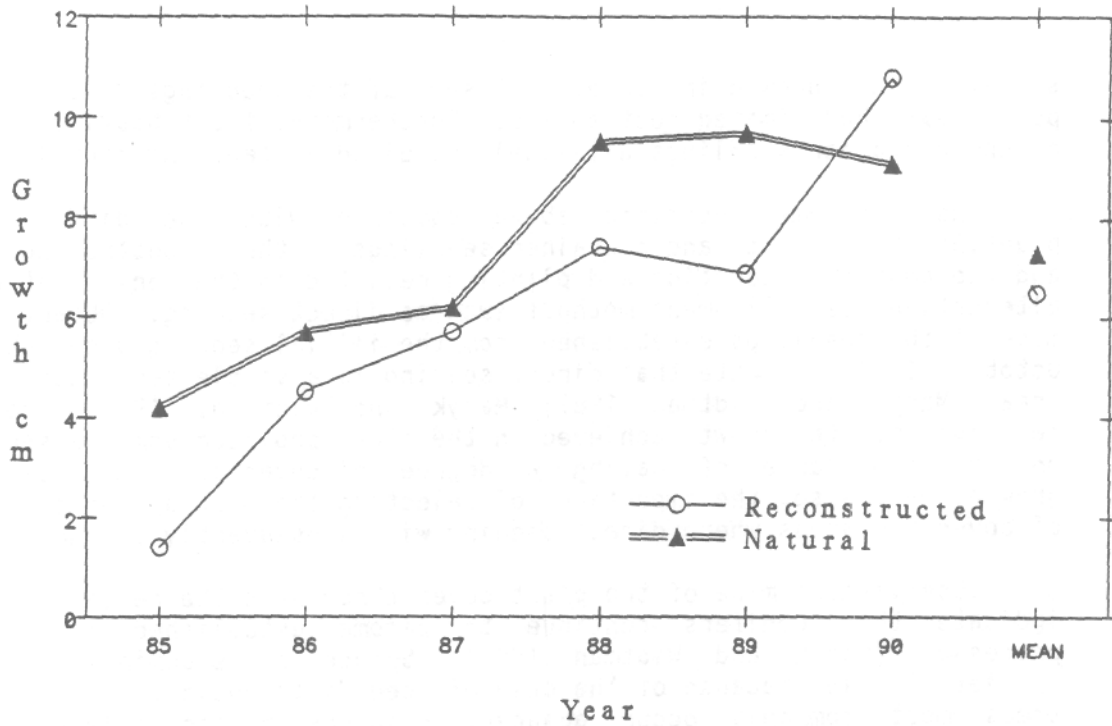


Figure 2. Annual and Mean Annual Growth of Pine on Reconstructed and Natural Soil at the Highwall Site.

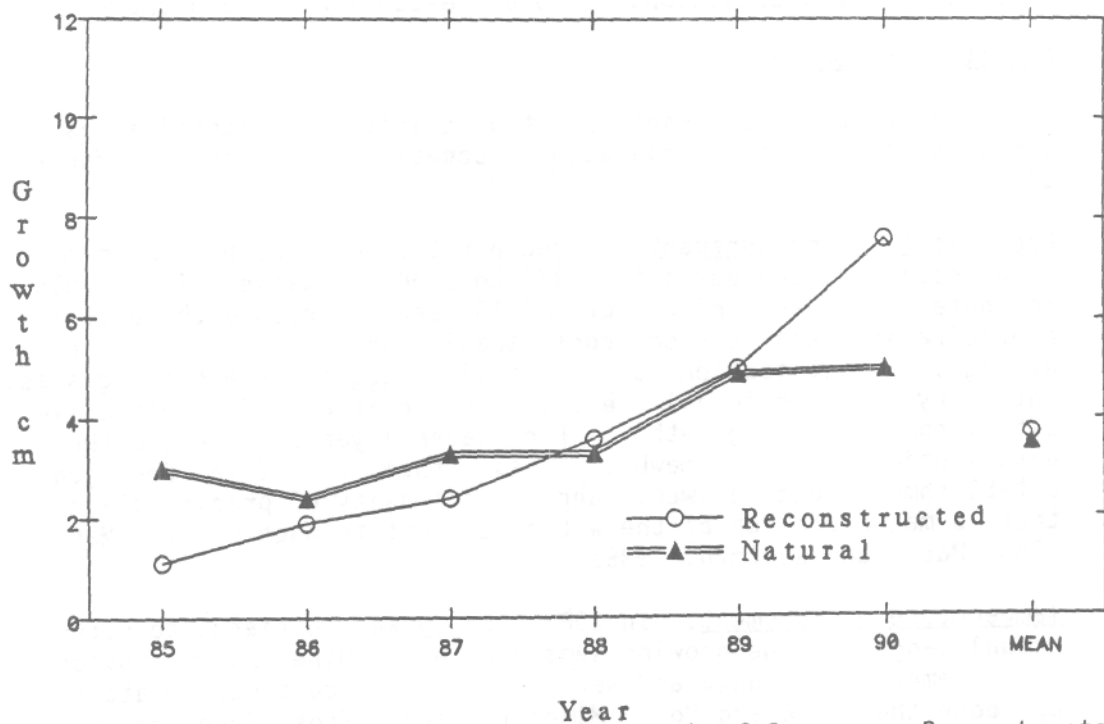


Figure 3. Annual and Mean Annual Growth of Spruce on Reconstructed and Natural Soil at the Highwall Site.

survival and growth indicated that some of the seedlings demonstrating poor growth had limited root egress. Furthermore, frost heaving of some of the container seedlings ultimately resulted in seedling mortality.

The problems described above combined with the difficulty in planting bare root and container seedlings in the reconstructed soils and the cost of production and planting resulted in the consideration of alternative establishment methods such as direct seeding. Observations made of the seedlings established from the initial seeding undertaken in October 1983 indicate that direct seeding is a viable technique in the area (Macyk and Widtman 1987; Macyk and Widtman, 1991). Results relative to the growth achieved in the plots provided some perspective on the importance of having a degree of cover to promote seedling growth, and also, the importance of selecting the most appropriate type of cover for areas where direct seeding will subsequently be undertaken.

Observations made of the plant cover throughout: the reclaimed areas indicate that conifers continue to become established by natural processes (Macyk and Widtman 1991). Spruce is the dominant invading species likely because of the ease of seed distribution. The invading trees most commonly occur adjacent to shrubs, particularly alder. A combination of soil and microclimatic conditions promotes this phenomenon. The soils supporting a shrub cover generally have better physical conditions and moisture and temperature extremes are not as pronounced as they would be in areas where shrubs are absent. However, some seedlings have become established and are thriving in areas that have very severe conditions for plant establishment and growth.

Climate Monitoring

Throughout the research study climate was recognized as the most limiting factor to reclamation success in the region (Macyk et al. 1989).

Precipitation measurement. Precipitation records have been maintained on a growing season basis for 1973 to 1990 inclusive. It is interesting to note that for nine out of 18 years of record the growing season precipitation was either considerably above or below the calculated average. Distribution of rainfall throughout the growing season and intensity of rainfall events are critical for effective plant establishment and growth. For several years of record the rainfall distribution was somewhat less than effective for good plant establishment and growth, and the intensity of precipitation was such that a major portion of the water was lost through runoff (Macyk et al. 1989; Macyk and Widtman, 1988a).

Temperature measurement. In 1983 a study was initiated to determine the actual length of the growing season at No. 8 Mine and to provide air and soil temperature data and set the stage for continuous data collection at both the No. 8 and No. 9 Mines to date. Frost-free period from] to 1990 inclusive ranged from 45 to 115 days with a mean of 83 days (Macyk and Widtman, 1991).

The soil temperature measurements emphasized assessment of temperature regimes on different slope aspects and the regimes associated with different types of vegetation cover. Measurements were also undertaken at the 0 (surface), 2 and 5 cm depths in coversoil and weathered spoil material.

The data indicated that high surface temperatures will impact vegetation establishment, growth and survival primarily on the south-facing slopes and at positions where the surface soil is relatively dark (Macyk et al. 1989). The temperature regimes under a grass/legume cover containing shrubs were more "moderate" and much less subject to wide fluctuations than the regimes associated with a grass/legume cover only.

The soil temperature data obtained forms an integral part of decision-making relative to species selection in different locations or settings.

CONCLUSIONS

This long-term research project which has addressed a number of issues, continues to monitor specific parameters and initiates research efforts to deal with additional concerns has drawn numerous conclusions. At the end of the first year of the study some conclusions were presented. These conclusions have been modified and expanded as the information generated increased. Readers are referred to the references cited to get more detailed information regarding specific topics.

Reclamation efforts in the Foothills/Mountains Region can be successful provided that appropriate procedures are utilized and a realistic time frame to achieve objectives is adopted. Soil management, selection of suitable seed and plant materials combined with an understanding of the influence of climate and the need to plan according to site specific conditions will result in the establishment of diverse plant communities and allow for different land use options.

LITERATURE CITED

- Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. 2nd ed. Agric. Can. Publ. 1646. 164 pp.
- Alberta Soils Advisory Committee. 1987. Soil quality criteria relative to disturbance and reclamation (Revised). Report prepared by Soil Quality Criteria. Working Group, Soil Reclamation Subcommittee.
- Canada Soil Survey Committee, Subcommittee on Soil Classification. 1978. The Canadian system of soil classification. Can. Dep. Agric. Publ. 1646. Supply and Services Canada, Ottawa, Ont. 164 pp.

- Canada Department of Agriculture. 1974. The system of soil classification for Canada. Publication 1455. Information Canada. Ottawa, 1974. 255 pp.
- Macyk, T.M. and Z.W. Widtman. 1991. Progress report, surface mine reclamation project, No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Environmental Research and Engineering Department. Report prepared for Smoky River Coal Limited. 60 pp.
- Macyk, T.M. and Z.W. Widtman. 1990. Progress report, surface mine reclamation project No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky River Coal Limited. 37 pp.
- Macyk, T.M. and Z.W. Widtman. 1989. Progress report, surface mine reclamation project, No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky River Coal Limited. 42 pp.
- Macyk, T.M., Z.W. Widtman and V. Betts. 1989. Impact of climate on reclamation success in the Foothills/Mountains region of Alberta, Canada. 1Q: Proceedings of "Reclamation, a Global Perspective" held in Calgary, Alberta, Canada, August 27 to 31, 1989.
- Macyk, T.M. and Z.W. Widtman. 1988a. Progress report, surface mine reclamation project, No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky Rver Coal Limited. 40 pp.
- Macyk, T.M. and Z.W. Widtman. 1988b. Soil survey and soil suitability evaluation for the No. 11 Mine area. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky River Coal Limited. 50 pp.
- Macyk, T.M. and Z.W. Widtman. 1987a. Progress report, surface mine reclamation project, No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky River Coal Limited. 45 pp.
- Macyk, T.M. and Z.W. Widtman. 1987b. Establishment of trees and shrubs on mined land in the Foothills/Mountains Region of Alberta, Canada. 1Q: Proceedings of the Combined Fourth Biennial Billings Symposium on Mining and Reclamation in the West and The National Meeting of the American Society for Surface Mining and Reclamation, Billings, Montana, March 17-19, 1987.
- Macyk, T.M. and Z.W. Widtman. 1986. Soil survey and soil suitability evaluation for the No. 12 Mine area. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky River Coal Limited. 79 pp.

- Macyk, T.M. and Z.W. Widtman. 1983 to 1986. Progress report, surface mine reclamation project, No. 8 and No. 9 Mines, Grande Cache, Alberta. Alberta Research Council, Terrain Sciences Department. Reports prepared annually.
- Macyk, T.M. and Z.W. Widtman. 1985. Soil survey and soil suitability evaluation for the No. 8 Mine area. Alberta Research Council, Terrain Sciences Department. Report prepared for Smoky River Coal Limited. 72 pp.
- Macyk, T.M. 1972 to 1982. Progress report, surface mine reclamation project, No. 8 Mine, Grande Cache, Alberta. Alberta Research Council, Soils Department. Reports prepared annually.
- Macyk, T.M. 1973. Soil survey of the No. 9 Mine area, Grande Cache, Alberta. Alberta Research Council, Soils Division. Report prepared for McIntyre Porcupine Mines Limited.
- Van Zalingen, S.F., T.M. Macyk and V. Betts. 1988. Factors influencing the native species invasion of a reclaimed subalpine minesite near Grande Cache, Alberta. In: *Proceedings of the Alberta Conservation and Reclamation Conference '88*, Lodge at Kananaskis, Alberta, September 22-23, 1988.