Reclamation in Mountainous Areas

Proceedings of the Sixth Annual Meeting of the Canadian Land Reclamation Association and the Fifth Annual British Columbia Mine Reclamation Symposium

Cranbrook, B.C.
August 24–27, 1981

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Ministry of Energy, Mines and Petroleum Resources

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EDITOR'S NOTE

These proceedings present the papers in chronological order. Papers have been briefly edited and re-typed. Time constraints prohibited final text proofreading by individual authors, consequently, the editor accepts responsibility for any errors.

OPENING REMARKS

J.C. ERRINGTON
CHAIRMAN
TECHANICAL AND RESEARCH COMMITTEE ON RECLAMATION

OPENING REMARKS

As chairman of the Technical and Research Committee on Reclamation it is my pleasure to welcome you to the Sixth Annual Meeting of the Canadian Land Reclamation Association and the Fifth Annual B.C. Mine Reclamation Symposium.

When the Technical and Research Committee on Reclamation agreed to act as the organizing committee for this meeting it did so with some degree of trepidation. We were concerned that an August meeting might not attract as wide an audience as our normal March venue.

I am pleased to see that these fears were unfounded and it is gratifying to see such a large turn-out.

The primary purpose for this symposium is to provide a forum for exchange of ideas on land reclamation, an objective that is shared by both the Canadian Land Reclamation Association and the Technical and Research Committee on Reclamation. For those of you who have regularly attended the B.C. Mine Reclamation Symposium I hope that this meeting will expose you to a wider perspective on reclamation matters. I also hope that you will enjoy seeing, first hand, the work of Cominco, Fording and B.C. Coal that you have heard mentioned so frequently during past meetings.

For those of you from out of Province, I welcome you to British Columbia and hope you will be able to appreciate some of our reclamation problems and attempts at their solution.

I would like to take this opportunity to thank the committee members for their contribution in making this symposium a reality. In particular, I would like to thank the registration coordinator, Art O'Bryan; the papers chairman, Roger Berdusco, who was assisted by Jack Thirgood; and the field trip coordinators, Bob Gardiner, Roger Berdusco and Tony Milligan.

We are also indebted to support and sponsorship from the Mining Association of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Canadian Land Reclamation Association, Cominco Ltd., Crowsnest Resources Ltd., Fording Coal Ltd. and B.C. Coal.

And last I would like to extend the appreciation of the Committee to the speakers, chairpersons and the many students who have helped make this symposium a success.

KEYNOTE ADDRESS

by

E.N. Doyle
Cominco Ltd.

KEYNOTE ADDRESS

Some months ago, Roger Berdusco of Fording Coal approached me with the request that I give a somewhat informal speech at the Canadian Land Reclamation Association's meeting to be held in Cranbrook. In a moment of weakness, without too much thought as to the enormity of the responsibility which was being vested in me by Roger, I agreed. On reflection, I would probably have been better off to decline gracefully since there are obviously a great number of people, many of them present here today, who could have spoken much more adequately about land reclamation and its implications in the Canadian scene.

However, having given my commitment, I will proceed to do what Roger has asked me to do and address myself to some items which could be construed as interesting to specialists in the art and science of reclaiming disturbed land.

For the past two days you have been regaled with sundry advice concerning the regulatory aspects of land reclamation, you have observed the process of natural revegetation of exploration trenches in Montana, you have controlled erosion in the Queen Charlottes and have listened, with bated breath, to various speakers who have itemized the mysteries of soil cultivation and seed selection for returning disturbed land to, at least, minimal productive capacity.

Additionally, many of you have got claustrophobia, sore feet and sunburn as a consequence of the field trip to Cominco's Sullivan mine and concentrator yesterday afternoon. Presumably, with representatives from so many parts of the country, this event will figure in the next Canada summer games.

According to information published recently by the Mining Association of Canada, the total land area occupied by mining operations in Canada, approximates 130,000 acres. This represents about 0.006 per cent of the total land area of Canada and compares with 30 million acres occupied by highways and 172 million acres devoted to farming. It is somewhat surprising to me that given this rather small area that outcries can arise from what we can only presume is an uninformed public. One does not hear a great deal of concern with respect to agricultural and industrial endeavours and particularly when these are in rather remote areas. Presumably, the mining industry has not done its homework with respect to public relations and it is hoped that this deficiency will be remedied through the various mining associations and mining companies throughout the country in the future. It is a known fact that some significant efforts in this information exchange field are being undertaken in more recent times.

There is one item which has been of consuming interest to me personally even though it is only remotely concerned with land reclamation. This issue has become one of the most emotionally charged environmental topics of our time. I refer, of course, to the Love Canal and to the problems which this particular disposal site has caused for all persons who have been in contact with it since the first placement of toxic wastes took place in 1942.

The saga of the Love Canal began many years ago. In the late 1800's, William Love had a dream about the utilization of the energy from Niagara Falls. He began work on the Canal in 1894 on the excavation of a canal which was designed as the primary source of power which, in conjunction with plans made by Elon Hooker of the Hooker Electrochemical Company, would bring unparalleled prosperity to a region which was ideally situated with respect to markets for the manufactured chemicals which were to be made by the company.

Because of the money situation at the time and compounded by the fact that the economic transmission of power over long distances was achieved, the project died in 1910. For the next 30 years, the completed portion of Love's Canal, located in an undeveloped area several miles from downtown Niagara Falls, served as a monument to William Love's dream.

In September 1941, Hooker initiated feasibility studies to determine the suitability of using the unfinished canal because its bottom and sides were of impermeable clay. It was determined that the canal was suitable as a disposal site for wastes from Hooker's Niagara Falls manufacturing operation. Since the canal had been dug out of clay it assured that the chemical waste would remain in place indefinitely. Through a series of legal problems involving title descriptions, the consumation of the sale of the property to Hooker was delayed until 1947.

From 1942 until 1953, the company used the site for disposal of waste materials from its Niagara Falls operation. Its use was superior to many methods of disposal used by industry at that time. Progressively, as Hooker disposed of wastes, the particular portion of the canal affected by the disposal was covered with a layer of the same clay material which formed the bottom and sides of the canal. It is of interest to note that the use of clay to contain chemical wastes meets, in every respect, pending Federal RCRA standards.

In 1952, the Niagara Falls Board of Education came to the conclusion that the general area around the Love Canal was going to continue to develop and it announced its intention to build a school in that neighbourhood. The School Board indicated that the canal property was the only area which was suitable for the school. The Board indicated that it was so desirous of acquiring the property that condemnation might be resorted to.

In March 1952, a Hooker executive visited the site with the Board Superintendent and President. Hooker had a map prepared showing where the wastes were deposited, how they were covered, and the results of testing which had recently been completed. On the map provided to the Board, it was stated that there was: "no evidence of chemicals any place digging down to ten feet right up to within one foot of the excavations. In places where we have dumped chemicals, the chemicals are almost unchanged in form and found four feet below top surface."

In October 1952, Hooker sent a letter to the Board confirming the company's understanding with the Board that the Love Canal property was to be used for a school:

... and the balance of the property to be maintained as a park.

... as explained to you at our conferences in view of the nature of the property and the purposes for which it has been in use, it will be necessary for us to have special provisions incorporated into the deed with respect to the use of the property and other pertinent matters.

Acknowledgement of the warning given by Hooker to the Board was made by the President of the School Board who specified that future members of the Board and other later owners of the Love Canal property would know that it was not suitable for construction because chemical wastes had been deposited there.

The deed from Hooker to the Board states, in part:

"Prior to the delivery of this instrument of conveyance (deed), the Grantee (Niagara Falls Board of Education) herein has been advised by the Grantor (Hooker Electrochemical Company) that the premises above described have been filled, in whole or in part, to the present grade level thereof with waste products resulting from the manufacturing of chemicals by the Grantor at its plant in the city of Niagara Falls, N.Y. and the Grantee assumes all risks and liability incident to the use thereof."

During the next few years, the Board allowed thousands of cubic yards of the canal cover to be removed; this is documented by the Board records.

In 1957, the Board was considering the transfer of unused sections of the canal property to private developers. At that time, a representative of Hooker appeared before the Board's regular meeting to remind the members of the possible dangers of using the Love Canal for construction because of the chemicals buried there. At that meeting, the Board directed that a letter be forwarded to Hooker "...expressing appreciation for sending their representative here tonight to explain the conditions of the soil near the 99th Street School when there was no legal obligation on their part to do so." All of this was reported to the public in the following day's issue of local and area newspapers.

A similar representation was made to the Board two weeks later by the Vice-President and General Counsel of Hooker Electrochemicals. They opposed the sale of the property and amplified the remarks made to the Board at the prior meeting. This second representation was acknowledged in the minutes of the School Board meeting at the appropriate time.

During the next few years, the city construoted two streets through the canal and, in 1968, the state of New York began construction of the La Salle expressway, which resulted in the relocation of another street through the southern portion of the canal.

It wasn't until 1976 that Hooker learned that chemicals were seeping out of the canal and into basements of some homes on the periphery of the Love Canal property. This was the first evidence that chemicals had migrated from the canal into adjacent properties.

A task force, formed in 1977, comprised of the city of Niagara Falls, the Niagara County Health Department and Hooker Engineers began to study the situation. The city, acting as lead, commissioned Calspan Corporation of Cheektowaga, N.Y. to prepare an abatement plan. Subsequently, the city commissioned Conestoga-Rovers of Waterloo, Ontario, Canada to prepare a remedial program. Three months later, Conestoga-Rovers presented its recommendations for a system to contain the wastes migrating from the canal. Hooker also participated in the study and offered to pay one third of the expected costs of remedial work to the southern section of the canal which is estimated at $840,000.

The recommended remedial engineering program was designed to collect and treat leachate formed when the canal cover was disturbed allowing rain and melted snow to fill the clay-lined canal and overflow much like a bathtub.

Testing has shown that even today the lower sidewalls and bottom of the canal are containing the waste materials as originally intended. Commencing August 2, 1978, the New York State Health Commissioner ordered the temporary closing of the 99th Street School (adjacent to the canal) and recommended the temporary evacuation of pregnant women and children under two years of age living in the first two rings of homes around the canal property (no homes were constructed on the canal).

One week later, Governor Carey visited the area and announced that 236 families in the first two rings of homes bordering the canal would be evacuated and their homes purchased.

There have been a number of studies since that date with respect to the health impact of the consequences of seepage from this storage area but, as appears to be common in these studies, there have been accusations of poor design and unwarranted conclusions from various studies on the basis of lack of scientific evidence.

It is paradoxical that, on June 30, 1980, William Sanjour, Chief of the E.P.A. Hazardous Wastes Implementation Branch, in discussing Hooker's use of the Love Canal reported in the New York Times that "Hooker would have no trouble complying with these (Federal RCRA regulations). They may have had a little extra paper work but they wouldn't have had to change the way they disposed of the waste."

In May 1980, President Carter declared a state of national emergency in the Love Canal area, paving the way for the temporary evacuation of up to 710 families. The same day, the U.S. Department of Health and Human Services released a special panel's assessment of the E.P.A. report and its conclusion was that the study:

> ... provides inadequate basis for any scientific or medical inferences from the data (even of a tentative or preliminary nature) concerning exposure to mutagenic substances because of residence in the Love Canal area.

> ... we do not believe that on the basis of this report it could be concluded that "chemical exposures at Love Canal may be responsible for much of the apparent increase" nor can we concur with the reports implication of cytogenic observations suggest that the residents are at increased risk of neoplastic disease, of having spontaneous abortions, and in having children with birth defects based on the evidence presented.

A similar report on the situation from the epidemiological viewpoint was announced by the New York Department of Health. This indicated that rates of miscarriage and birth defects for the entire Love Canal area were normal. The study also concluded that there was no evidence linking any health problems which do exist to the migration of chemicals from the Love Canal.

The New York Department of Health report concluded:

> ... Finally, and most importantly, we have not yet been able to correlate the geographic distribution of adverse pregnancy outcomes with chemical evidence of exposure. At present, there is no direct evidence of a cause-effect relationship with chemicals from the canal.

This position was reaffirmed in October 1980, when a special panel of prominent physicians appointed by New York Governor Carey reviewed previous Love Canal health studies. The panel was particularly critical of two studies which had been earlier used as the basis for the evacuation of Love Canal residents.

These then are some of the facts, as I see them, with respect to the Love Canal. What conclusions can be reached?

The original containment was good; the migration of chemicals from the canal occurred because of a failure of others to properly maintain the site after the company no longer owned the property and despite repeated warnings by the company. In all respects, it would appear the company acted properly and responsibly.

Many of the comments which I have used are taken from an article published in Chemteck of December 1980. The article was provided by Mr. T.L. Baeder who was, until September 1980, President and Chief Operating Officer of Hooker Chemical.

There is of course, a tendency, as is evident when you read Mr. Baeder's article, for any corporation or any individual to over-react in terms of self-defense. This is understandable and sometimes commendable. It does, however, illustrate that each of us has a serious responsibility with respect to the future as it relates to land reclamation and, furthermore, technology and professionalism used today may well be inadequate for the demands and expectations of future generations.

In conclusion, I wish to thank you for your kind attention, and to wish you a very pleasant day tomorrow on your field trip to Fording Coal and B.C. Coal. I am sure you will find that both of these corporations have done a great deal, in terms of practical, applied land reclamation technology to justify this day which you will spend at these two properties. Thank you.

PRESENTATION OF THE ANNUAL
B.C. MINE RECLAMATION AWARDS

MINE RECLAMATION AWARDS

TERMS OF REFERENCE

Under the auspices of the British Columbia Ministry of Energy, Mines and Petroleum Resources, and the Mining Association of British Columbia, a Reclamation Award has been established to recognize outstanding achievement in mine reclamation in British Columbia. In addition to this award, three citations are given to recognize merit in mining reclamation. The guidelines for these awards are as follows:

1. Nominations will be solicited from Ministry of Energy, Mines and Petroleum Resources' Inspectors. In addition, nominations may be made by companies with respect to their own work, or work done by individuals or organizations familiar with the goals of reclamation.

   Nominations should be submitted in writing to:

   Chairman, Awards Subcommittee
   c/o Technical and Research Committee
   Ministry of Energy, Mines and Petroleum Resources
   Inspection and Engineering Branch
   525 Superior Street
   Victoria, B.C.
   V8V 1T7

   In the nomination, documentation of the reclamation achievement must be outlined and reasons proposed why the project or program merits recognition.

2. The reclamation project may be major or minor in extent and may be the result of one person's activities.

3. The Technical and Research Committee will decide the winner of the Reclamation Award and the three Citations.

4. The Reclamation Award and Citations will be awarded each year at the annual Mine Reclamation Symposium.

5. The Reclamation Award cannot be won by a mining company two years in succession. Citations may be won in successive years.

6. Deadline for receipt of nominations for the awards is January 31 of the year the award will be given.

REPORT OF THE AWARDS SUBCOMMITTEE
TECHNICAL AND RESEARCH COMMITTEE ON RECLAMATION

The Awards Subcommittee has reviewed all nominations for the Reclamation Award and Citations and, as in past years, many of the choices were difficult.

CITATIONS

Citations will be presented this year in the categories of Exploration, Metal Mining and Coal Mining.

Exploration
The 1980 Citation is presented to SAGE CREEK COAL

Sage Creek Coal Ltd. with their reclamation specialist, Mr. Alan Lamb, have conducted an excellent reclamation program on their Sage Creek property. They have demonstrated that with the application of appropriate technology disturbed exploration areas can be effectively revegetated. All 77 ha of disturbance have now been reclaimed.

Metal Mining
The 1980 Citation for Metal Mining is presented to NEWMONT MINES LTD. - Similkameen Division

Newmont has carried out extensive reclamation programs for the past five years on their Similkameen property and now have revegetated 121 ha of disturbance. In addition, they accepted responsibility for reclaiming one of Granby's 29 ha tailings pond which has now been successfully revegetated.

Their reclamation program has involved top dressing the faces of waste rock dumps with fine-textured glacial till and aerially applying seed and fertilizer by fixed-wing aircraft.

They have obtained excellent growth and are well on their way to achieving their goal of establishing grazing land.

Coal Mining

The 1980 Citation for Coal Mining is presented to B.C. COAL

The reclamation program at B.C. Coal has been ongoing for a decade and during this period a total of 1,000 ha of land has been revegetated.

They have recently made a concentrated effort to revegetate all exploration disturbances made since the first years of exploration.

B.C. Coal is continuing their excellent research program utilizing the expertise of the academic world and have endeavoured to translate this knowledge to a practical level. The research studies presently being carried out attempt a "total ecosystem" approach and will hopefully answer questions of ecosystem structure, function, dynamics, stability and succession.

Honourable mention is given to FORDING COAL

RECLAMATION AWARD

The 1980 Reclamation Award is presented to ISLAND COPPER

The Island Copper Mine, situated near Port Hardy, has instituted and are undertaking a progressive reclamation program.

The success they have had can be attributed primarily to their program of recontouring their waste dumps and covering the waste rock with glacial till and topsoil. A program of seeding and fertilizing with agronomic species followed by planting alder and conifer seedlings has resulted in excellent growth and, to date, a total of 67 ha have been reclaimed.

Revegetated sites help to support a population of up to twenty blacktail deer which are frequently seen grazing on the reclaimed areas.

They are currently stockpiling 2.2 million tons of glacial till, topsoil and peat for use in reclamation programs.

A small section of the beach dump was resloped; grasses, legumes and trees were planted. This test demonstrated that the beach dump could be reclaimed and a complete marine environment could be established.

Their progress toward the re-establishment of forest land will serve as a model for other mines in British Columbia.

BRITISH COLUMBIA MINE RECLAMATION, AN OVERVIEW

by

J.D. McDonald, P.Eng.
B.C. Ministry of Energy, Mines and Petroleum Resources

BRITISH COLUMBIA MINE RECLAMATION, AN OVERVIEW

INTRODUCTION

The Province of British Columbia encompasses 948,569 square kilometers and contains a great diversity of physiographic regions (Figure 1).

The climate varies from the Mediterranean-like Juan de Fuca Strait on the southwest coast where temperatures seldom go below freezing and rainfall is less than 75 cm per year, to the extreme cold of the north-east where winter temperatures drop to minus 50°C. Figure 1 illustrates the different physiographic and climatic characteristics of the province.

There are areas of rain forest on the Pacific Coast where the annual precipitation can exceed 350 cm. In contrast, the southern interior plateau east of the coastal mountains receives less than 30 cm (Figure 2). The province's vegetation reflects these extremes of climate, from the coastal rainforests to the northern alpine tundra with sporadic permafrost, and the southern interior dry bunchgrass areas which in summer resemble deserts.

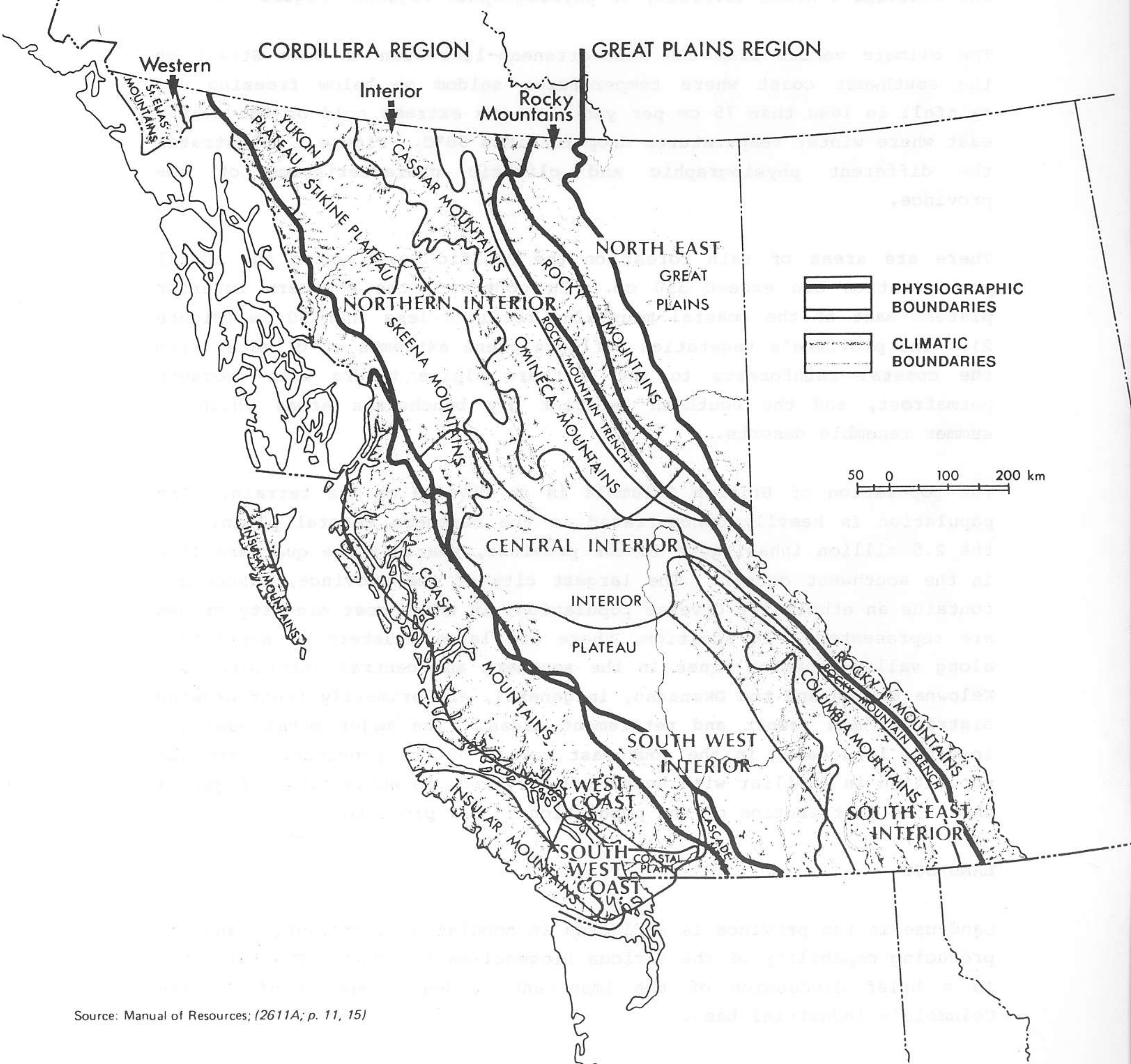
The population of British Columbia is as diverse as its terrain. The population is heavily concentrated in the southern coastal plain: of the 2.5 million inhabitants in the province, nearly three quarters live in the southwest corner. The largest city of the province, Vancouver, contains an ethnically diverse population, in which most minority groups are represented. In addition, there are large clusters of settlement along valley-oriented lines in the southern and central interior. The Kelowna region and the Okanagan, in general, are primarily fruit-growing districts, and resort and retirement areas. The major metal smelting industry is located in the southeast corner of the province: here the population is familiar with heavy industry and its activities. Figure 3 shows the distribution of the population in the province.

LAND-USE

Land-use in the province is reflected in population distribution and the producing capability of the various biogeoclimatic zones. The following is a brief discussion of the important land-use aspects of British Columbia's industrial base.

Figure 1

BRITISH COLUMBIA
PHYSIOGRAPHIC AND CLIMATIC REGIONS



Source: Manual of Resources; *(2611A; p. 11, 15)*

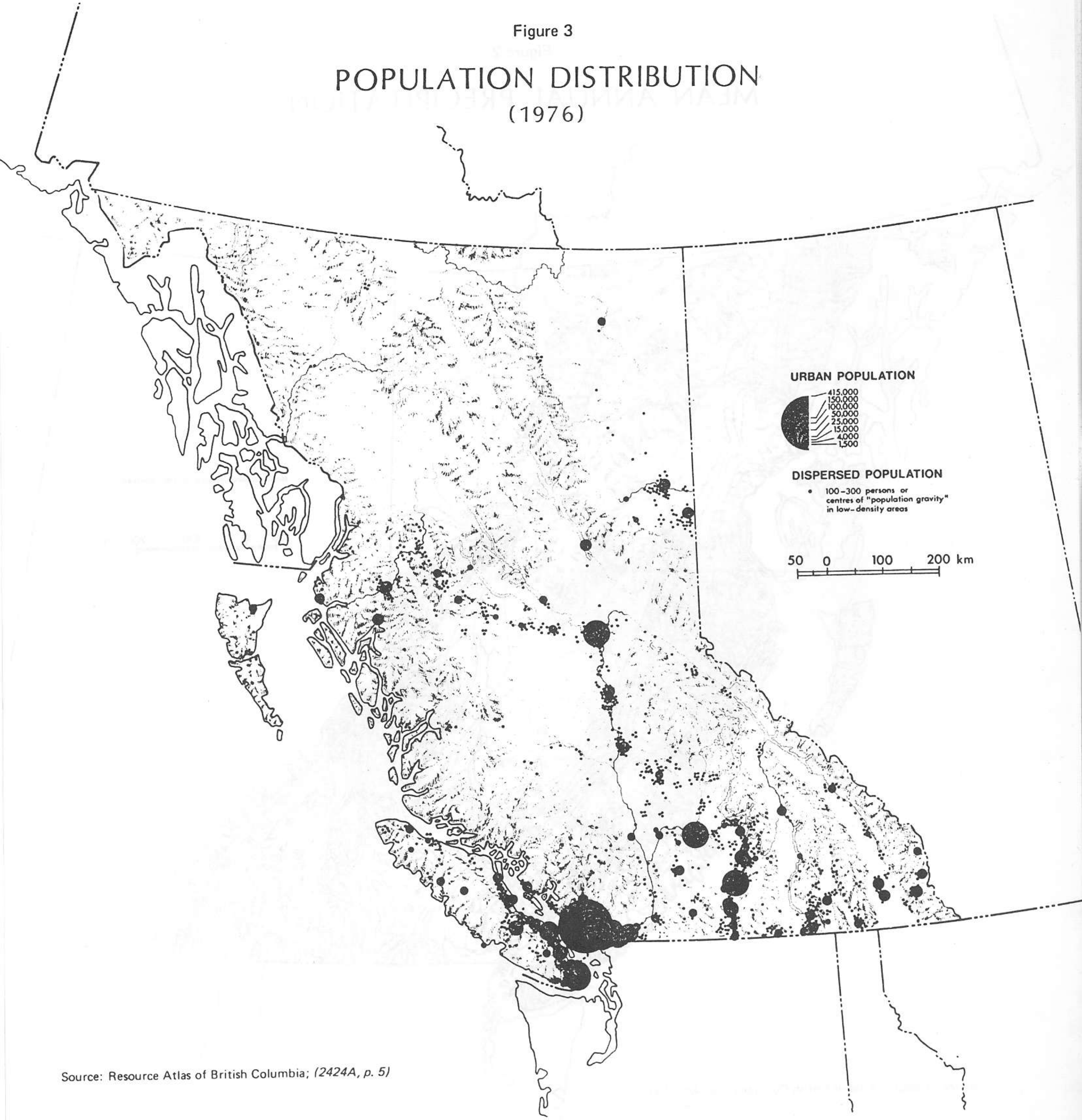
Figure 2

MEAN ANNUAL PRECIPITATION

Source: Resource Atlas of British Columbia; *(2424A; p. 43)*

Figure 3

POPULATION DISTRIBUTION
(1976)



Source: Resource Atlas of British Columbia; *(2424A, p. 5)*

FORESTRY

British Columbia's vast forests provide the natural resources for the province's largest industry. Fifty-five per cent of the provincial land area is forested, mostly with stands of coniferous trees. The coastal forests from Prince Rupert south to the Washington border, because of their large stands of timber, milder climate and plentiful rainfall are the most productive. However, the interior forests are becoming more important, to the point that in 1976 the provincial harvest was nearly evenly distributed between the coast and the interior (Figure 4).

MINING

Mining ranks second after forestry as a generator of provincial wealth. It has grown in annual value from $30 million in 1910 to a value of $1.4 billion in 1979. Because it is a non-renewable resource, the pattern of mining land-use has tended to vary over the decades as deposits are brought into production, mined and abandoned. Open-pit production of base metals and coal has characterized the industry in British Columbia over the past two decades. During this period iron and copper deposits have been developed on the south coast. In the Kootenays, lead and zinc production has declined while coal has increased, and the vast Liard Mining Division in the northeast section of the province has come into prominence. In addition, there is asbestos at Cassiar, accounting for eight per cent of Canadian production and precious and base metal mines in the Portland Canal area. The oil and gas fields in the Peace River region of northeastern British Columbia are of enormous importance to the province.

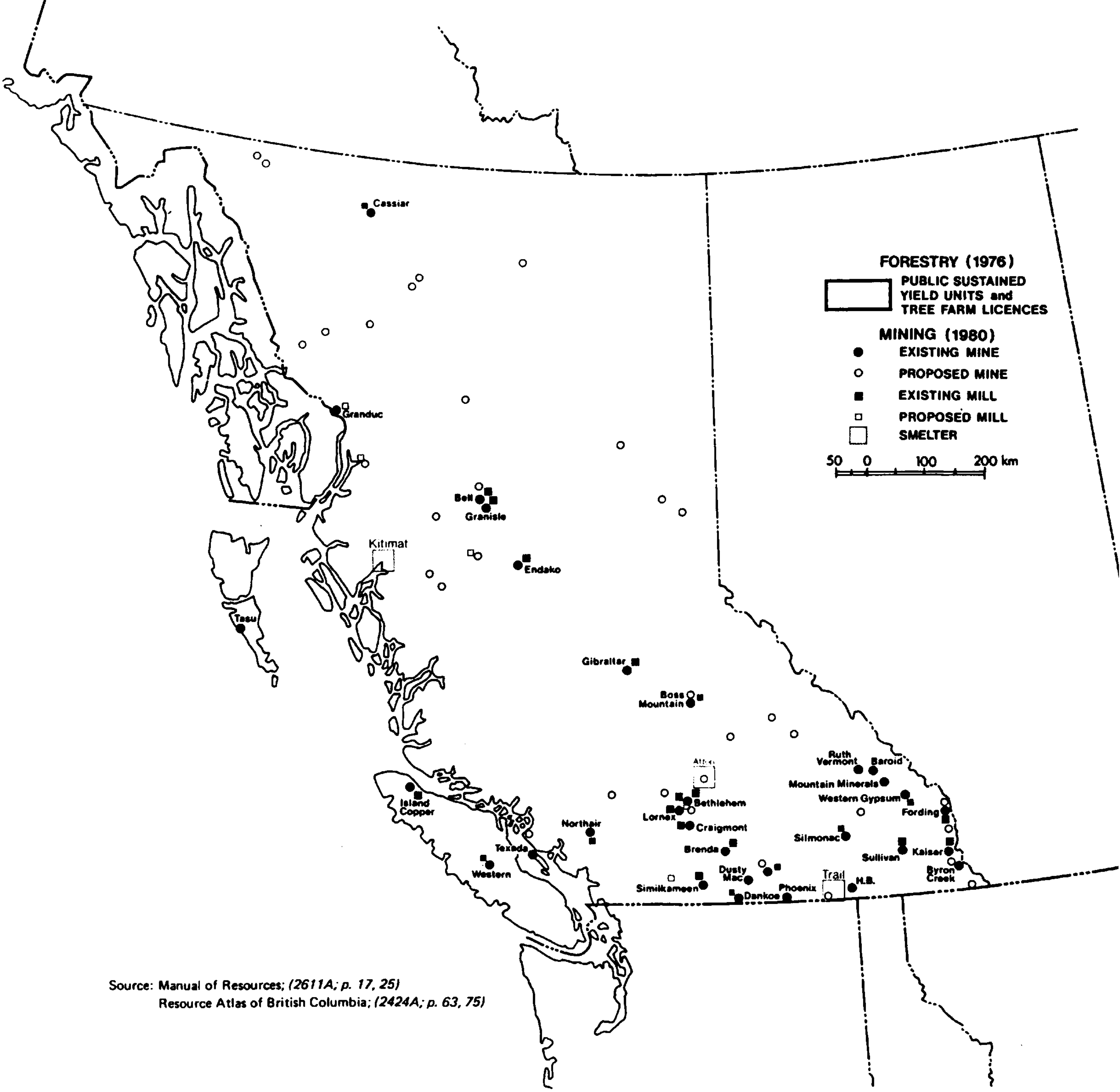
The Mining Association described the present status of the mining industry in British Columbia as follows:

> "Mining in British Columbia received its initial impetus from coal deposits on Vancouver Island and alluvial gold discoveries on the Fraser River and its tributaries, in the mid 1800's. The mining industry has grown from these beginnings to the second largest industry in British Columbia with a gross value of production of $1.34 billion in 1978 with direct employment of 15,587 people and estimated additional indirect employment of 40,000 people in associated businesses in the province, and in Canada as a whole another 110,000 people."

2

Figure 4

FORESTRY AND MINING



Source: Manual of Resources; *(2611A; p. 17, 25)*
Resource Atlas of British Columbia; *(2424A; p. 63, 75)*

AGRICULTURE

Arable land inside the boundaries of British Columbia's agricultural land reserves is only 4.6 million hectares of the total 95 million hectare provincial total. Most of this productive land is located in river deltas, inter-mountain valleys, the interior plateau and the northeastern plain. A further 10 million hectares are rangelands used for domestic and wild animal grazing, much of which is forested (Figure 5).

GEOLOGY

The plate tectonics model for the western cordillera is of considerable importance in understanding the evolution of this region. This model essentially proposes that the different belts or terrains of this region were not derived in situ, but were rafted into their present position by plate tectonics and eventually docked and fused together to form a part of the province. Thus all or part of the different belts may have originated hundreds of kilometers away and brought very diverse geology and mineral deposits into contact with each other.

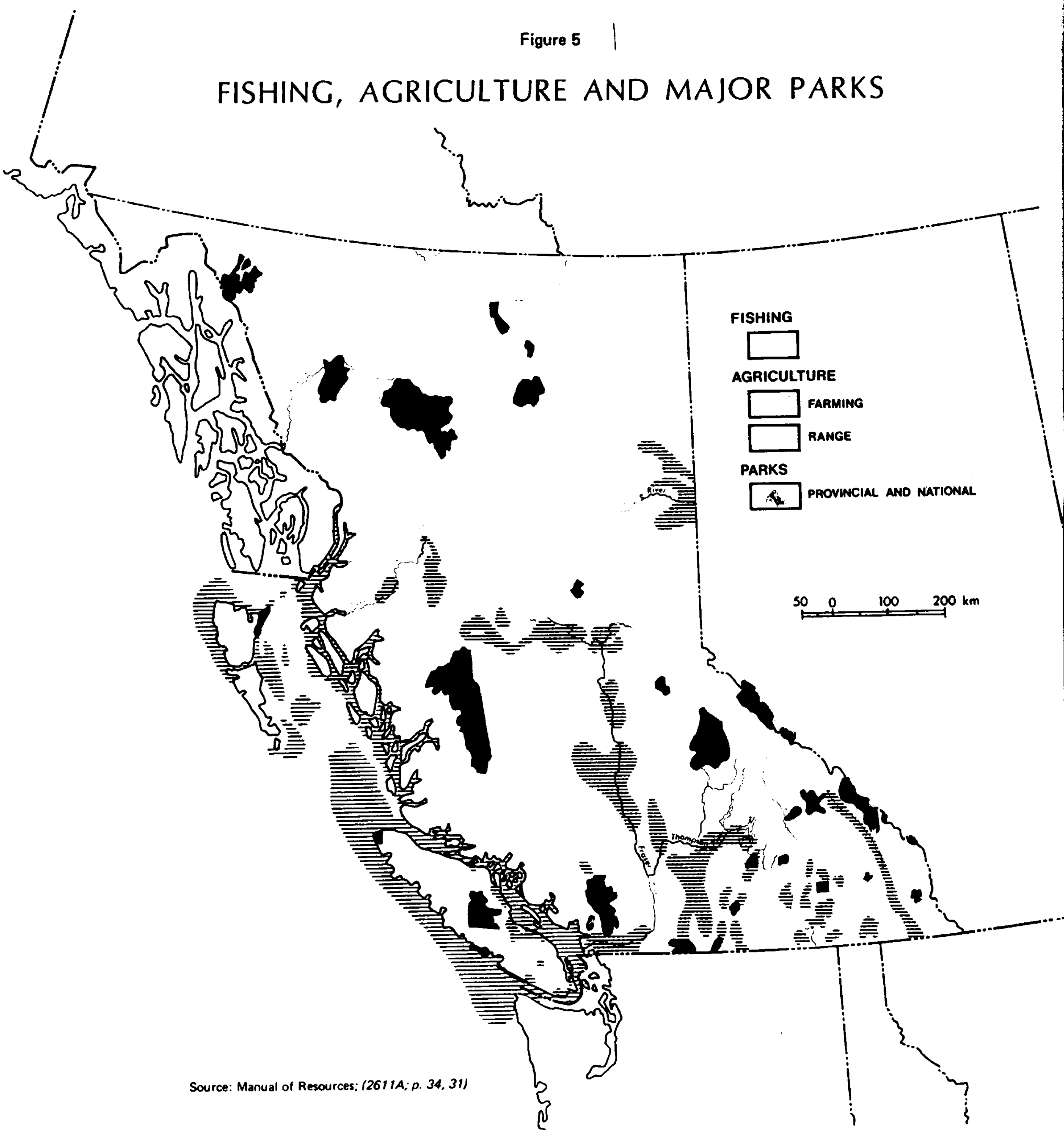
The eastern marginal belt consists of a continuation of the westward thickening sedimentary wedge which underlies the great plains of western Canada but with increasingly greater amounts of shales to the west. Volcanic rocks are rare, the area is strongly deformed but not metamorphosed.

The Omineca belt is composed of very strongly deformed and commonly highly metamorphosed volcanic and sedimentary rocks of Precambrian to early Mesozoic age. Granite instrusions are very common in this belt. Major regional uplift and erosion affected this terrain during the late Mesozoic period. In the tertiary, continental sedimentation and volcanoes were widespread in the western part of this region.

The Intermontane belt contains a series of late Paleozoic to mid-Mesozoic marine volcanic and sedimentary rocks. Many geologists consider the sequence to be an ancient volcanic island terrain which is overlain by continental sedimentary and volcanic rocks of mid-Mesozoic to mid-Tertiary age. These later continental rocks were deposited in what is known as "successor basins".

Figure 5

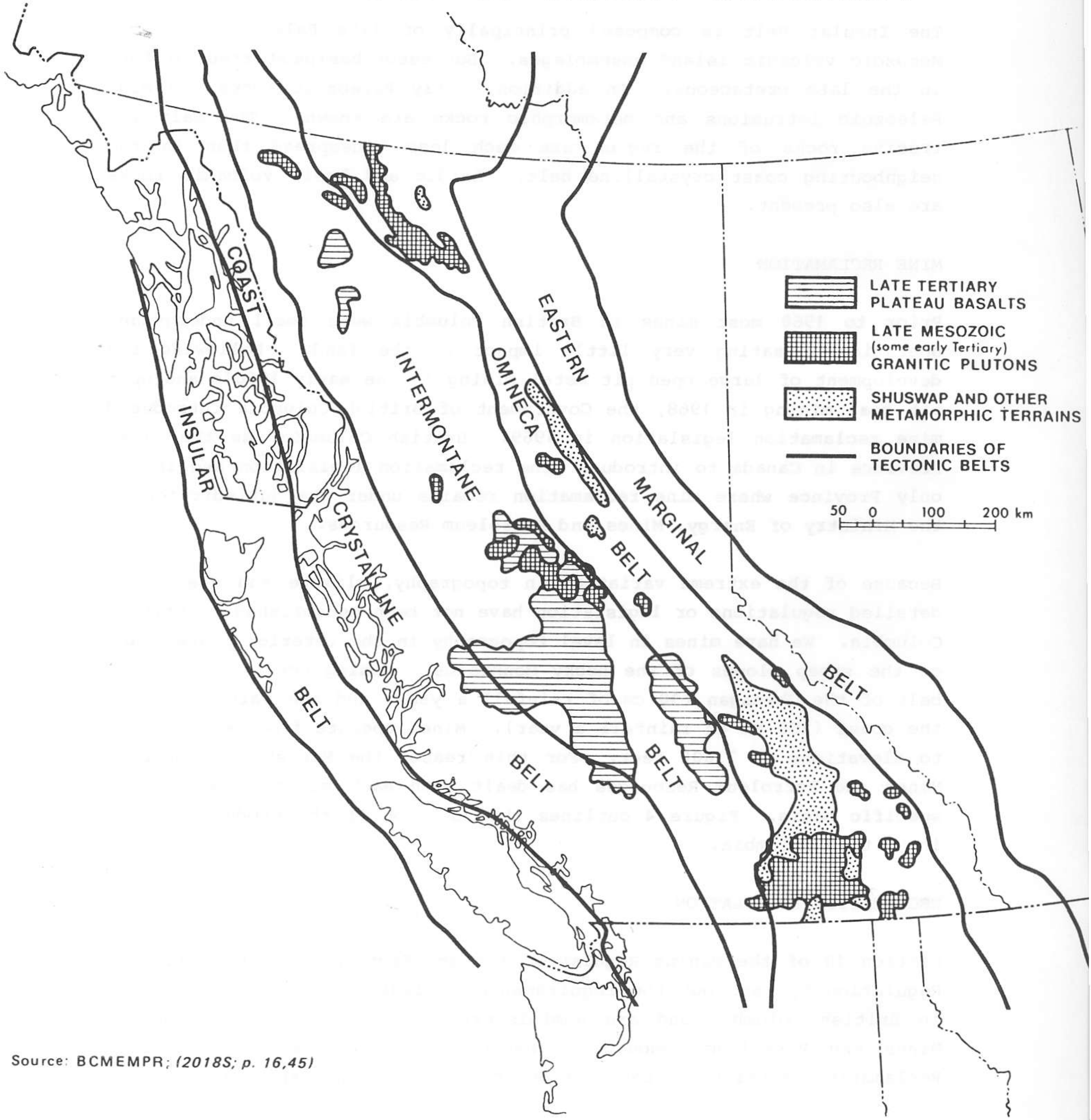
FISHING, AGRICULTURE AND MAJOR PARKS



Source: Manual of Resources; *(2611A; p. 34, 31)*

Figure 6

GEOLOGY OF BRITISH COLUMBIA



Source: BCMEMPR; *(2018S; p. 16,45)*

The Coast Crystalline Belt is an enormous batholith of granitic rock of mid-Mesozoic to early tertiary age. Remnants of Mesozoic volcanic rocks have been found within this batholith.

The Insular Belt is composed principally of late Paleozoic to mid-Mesozoic volcanic island assemblages. Successor basins started to form in the late cretaceous. In addition, early Paleozoic rocks and mid-Paleozoic intrusions and metamorphic rocks are known. The main intrusive rocks of the region are much less widespread than in the neighbouring coast crystalline belt. Acidic and basic volcanic rocks are also present.

MINE RECLAMATION

Prior to 1960 most mines in British Columbia were small underground operations creating very little impact on the land. Following the development of large open pit metal mining in the early 1960's and open pit coal mining in 1968, the Government of British Columbia introduced mine reclamation legislation in 1969. British Columbia was the first Province in Canada to introduce mine reclamation legislation and is the only Province where mine reclamation remains under the jurisdiction of the Ministry of Energy, Mines and Petroleum Resources.

Because of the extreme variation in topography, climate and elevation, detailed regulations or legislation have not been established in British Columbia. We have mines in level topography in the interior plateau and on the steep slopes of the Rocky Mountains. Mining occurs in the dry belt of the Okanagan (30 cm of rainfall a year) and the rain forest of the coast (350 cm of rainfall a year). Mines operate from sea level up to elevations of 7,000 feet. For this reason the Ministry of Energy, Mines and Petroleum Resources has dealt with each minesite on a site-specific basis. Figure 4 outlines the location of the producing mines in British Columbia.

RECLAMATION LEGISLATION

Section 10 of the Mining Regulation Act and Section 9 of the Coal Mine Regulation Act set out the requirements of legislation for reclamation in British Columbia and are administered by the Ministry of Energy, Mines and Petroleum Resources, Inspection and Engineering Division, Reclamation Section. Legislation covers mineral exploration, coal exploration, placer mining, quarries, gravel pits, metal mines and coal mines.

As a basic statement of policy, both Acts begin:

> "It is the duty of every owner, agent, or manager of a mine to institute and carry out a programme for the protection and reclamation of the surface of the land and watercourses affected thereby, and, on the discontinuance or abandonment of a mine, to undertake and complete the programme to leave the land and watercourses in a condition satisfactory to the Minister..."

Briefly, both Acts provide for the following:

1. A report to be submitted to the Minister of Energy, Mines and Petroleum Resources prior to the commencement of operations containing:

    a. A map showing the location and extent of the mine, and the location of lakes, streams and inhabited places in the vicinity.

    b. Particulars on the nature of the mining operation including the anticipated area to be occupied during the lifetime of the mine.

    c. Particulars on the nature and present uses of the land to be used.

    d. A programme for land reclamation and conservation with particular reference to:

        i. the location of the land.

        ii. the effect of the programme on livestock, wildlife, watercourses, farms and inhabited places in the vicinity of the mine, and the appearance of the mine site.

iii. the potential use of the land, having regard to its best and fullest use, and its importance for existing and future timber, grazing, water, recreation, wildlife and mining.

2. Review of the report by a standing committee composed of other resource agencies in the case of producing mines and coal exploration, and a referral system to those agencies in the case of mineral exploration.

3. A bond not exceeding $2,500 per hectare of disturbance.

4. Issuance of a surface work permit with such special terms and conditions as the Minister sees fit to prescribe.

5. Continual and progressive reclamation over the life of the mine, and the annual submission of a report on the progress of reclamation research and operations.

6. Closure of the mine and forfeiture of the bond in the case of non-compliance with any sections of the Act or permit.

Table 1 and Table 2 outline the process of the permit system.

In essence, the approach taken in formulating the legislation was to avoid setting any firm regulations until investigation and research had been carried out by each mining company to determine what could and must be done to adequately reclaim the disturbed land. In recognition of the varied geographic and environmental conditions that prevail across the province, the onus was placed on the industry to develop reclamation technology in cooperation with the Ministry of Energy, Mines and Petroleum Resources.

Closely associated with reclamation of disturbed lands is the construction of tailings impoundments and mine dumps, because in the final stage of these structures, revegetation will be necessary. In these projects, where their size can place them amongst some of the largest man-made structures, it is incumbent on the Inspection and Engineering Branch to ensure that these structures are being designed and constructed in accordance with acceptable engineering practices. An example is the construction of the L - L starter dams for Lornex Mining

TABLE 1

PERMIT PROCESSING FOR COAL EXPLORATION, COAL AND METAL MINES

APPLICATION FOR PERMIT SUBMITTED
TO MINISTER OF ENERGY, MINES AND PETROLEUM RESOURCES

↓

REVIEW BY RECLAMATION SECTION

↓

REVIEW BY ADVISORY COMMITTEE
ON RECLAMATION

↓

RECOMMENDATIONS ON APPLICATION SUBMITTED
TO THE MINISTER FOR APPROVAL

↓

APPROVED APPLICATION RETURNED TO
RECLAMATION SECTION FOR PROCESSING

↓

ORDER - IN - COUNCIL

↓

RECLAMATION SECTION ADVISES COMPANY
OF APPROVAL AND REQUESTS REQUIRED BONDING

↓

PERMIT ISSUED ON RECEIPT OF BONDING

↓

ANNUAL REPORTS REQUIRED TO DETERMINE
PROGRESS OF RECLAMATION. BONDING MAY
BE INCREASED OR DECREASED.

TABLE 2

PERMIT PROCESSING FOR MINERAL EXPLORATION, QUARRIES, GRAVEL PITS, PLACER MINING

APPLICATION FOR PERMIT SUBMITTED
TO CHIEF INSPECTOR OF MINES

↓

REVIEWED BY RECLAMATION SECTION
TERMS, CONDITIONS AND BONDING SET

↓

RECOMMENDATIONS TO THE CHIEF INSPECTOR
FOR APPROVAL OF PERMIT

↓

RECLAMATION SECTION ADVISES COMPANY OF
APPROVAL AND REQUESTS REQUIRED BONDING

↓

PERMIT ISSUED ON RECEIPT OF BONDING
UNDER THE AUTHORITY OF THE CHIEF INSPECTOR

Note:

1. Permits are only required when there is more than minimal disturbances and mechanical equipment is used.

2. For large mining companies with a number of exploration projects a General Reclamation Exploration Permit is issued covering all projects. A $5,000.00 bond is required.

Corporation Ltd., which when completed in the final mining phase, will be 320 meters long, 160 meters high and will impound 1.8 billion tonnes of tailings.

GUIDELINES FOR COAL DEVELOPMENT

Large-scale coal mine developments will have considerable impact on the natural, social, and economic conditions in the region of development. In recognition of this fact, a comprehensive set of guidelines has been prepared to assist coal companies in the preparation of environmental impact assessments of their proposed developments.

It should be noted from the outset that the guidelines for environmental impact studies are broad in scope, covering the major economic, social, and natural environmental implications of coal development. Coal developments should conform to the principles of integrated resource planning, principles which seek a balance between economic, social, and environmental goals. Thus, net economic benefits of coal development must be carefully weighed against the environmental and social costs before final decisions are made.

It should also be noted that the guidelines cover all related components of the coal development program, not just the coal mine, waste dump areas, processing plants, etc., but also off-site activities such as new transportation networks, shipping terminals, community development, power and power supply corridors, and any ancillary industrial activity generated in the region as a result of the coal development impetus.

Thus, the environmental impact assessment should not be received as a set of narrowly based studies on the impacts of coal development on the natural environment, prepared late in the engineering feasibility study process. Rather, it should be thought of as a planning tool that shapes the whole development program from its inception to be responsive to the economic, social, and environmental goals of the region of development.

The environmental guidelines for coal development are produced under the authority of the Environment and Land Use Committee, a Cabinet Committee of the Government of British Columbia. The Environment and Land Use Committee comprises seven ministers representing nine departments that are responsible for resource use and economic development, as well as matters dealing with major public facilities such as highways, settlement, and public health services. Under the Environment and Land Use Act, the Committee is responsible for integrated land and resource use planning in the Province and ensuring that the environmental impacts of all major resource developments are fully assessed.

Although the Environment and Land Use Act supersedes all other Provincial legislation, various departments are responsible for Statutes relating to specific aspects of coal development. Coal companies are required to apply for permits and licences for both exploration (under the Coal Act) and for development and reclamation (under the Coal Mine Regulation Act).

PROCEDURES FOR OBTAINING APPROVAL OF METAL MINE DEVELOPMENT

A guidelines procedure was instituted by the Ministry of Energy, Mines and Petroleum Resources in 1979 for proposed metal mine projects. The procedure calls for a preliminary feasibility (Stage I) and the final project design (Stage II) and is similar in many respects to the Guidelines for Coal Development. Because metal mining projects may vary widely in their size and in the magnitude of environmental impact, the procedure was designed to be flexible. Projects of low environmental and social impact are able to by-pass the Stage II review and apply directly for permits.

GUIDELINES FOR COAL AND MINERAL EXPLORATION

In order to accommodate the requirements of other Ministries, and to provide general guidance to companies, procedures of administration and good practice were summarized in a booklet entitled, "Guidelines for Coal and Mineral Exploration." These guidelines will be replaced by separate guidelines for coal exploration and for mineral exploration. These guidelines must be interpreted in the light of site-specific conditions. In general they recommend that the following points must be considered in the construction of roads, drill sites, adits and trenches:

- Minimization of the extent of land disturbance through geological mapping, pre-planning and engineering of layout, and close supervision of work.

- Utilization of the least disturbing means available when working in areas with sensitive resource conflicts, such as wildlife and fisheries.

- Drainage control by provision of ditching, culverts, and water bars where necessary.

- Minimization of disturbance in alpine areas.

- The necessity for site preparation prior to seeding and fertilizing.

New exploration techniques are now available for the minimization of land disturbance and in the provision of access into remote areas. Helicopter supported drilling costs including crew transportation vary from $50 to $100 per foot drilled and may go as high as $200 per foot drilled. This procedure eliminates the cost of road construction and the necessity for reclamation and protective measures. Helicopter supported drilling is not feasible where concentrated drilling is required.

The reclamation section encouraged and in some cases requested hand trenching as opposed to trenching by mechanized means. Where mechanical trenching is required, the use of a back-hoe is required, as this machine reduces the area disturbed, and it can be more selective in the excavation and replacement of rock, overburden and top soils.

With respect to adit sites, proposed locations were inspected and approved prior to start of work. Directions were given for adequate disposal of rock spoil and oxidized coal waste. Adits on steep terrain sometimes require waste rock or coal to be hauled to flatter terrain for burial.

Drill sites have proved to be easier to reclaim than adit sites. Except for the need to create a flat work space, they have not generated large amounts of disturbed earth. Only on steep slopes have problems been encountered.

Reclamation inspection is now more rigorous, resulting in more stringent requirements than in past years. Instructions are routinely given for site preparation and methods for the revegetation on sensitive areas, in particular, alpine regions. These instructions have included resloping and recontouring of roads, trenches and adit sites. Companies are required to return topsoil where possible, harrow and apply site-specific seed mixtures and fertilizers where necessary.

RECLAMATION ACHIEVEMENT IN BRITISH COLUMBIA

The Ministry of Energy, Mines and Petroleum Resources has directed most of its activity toward enforcement of reclamation of coal mines. The many proposed coal projects have necessitated that a strong emphasis be placed on coal mine reclamation.

There are many examples of excellent progress in reclamation within the British Columbia mining industry. For the past four years a mine reclamation award and two to three citations have been presented each year for outstanding achievement.

RECLAMATION IN THE MOUNTAINS OF NORTHEASTERN NEW MEXICO

by

Marcia Hamann Wolfe
Kaiser Steel Corporation

RECLAMATION IN THE MOUNTAINS OF NORTHEASTERN NEW MEXICO

ABSTRACT

Initial reclamation efforts in the mountainous area of northeastern New Mexico have proven successful at Kaiser Steel Corporation's York Canyon Coal Mines. The use of all native plant species for revegetation and a special mulching technique have minimized erosion problems. Partial highwall retention is being used to blend mined areas into the rugged physiognomy of the surrounding country. In addition to the placement of rock highwall and outcrop, rock piles have been located to create additional edge effect for the primary postmine land uses of wildlife habitat and native rangeland for cattle grazing.

INTRODUCTION

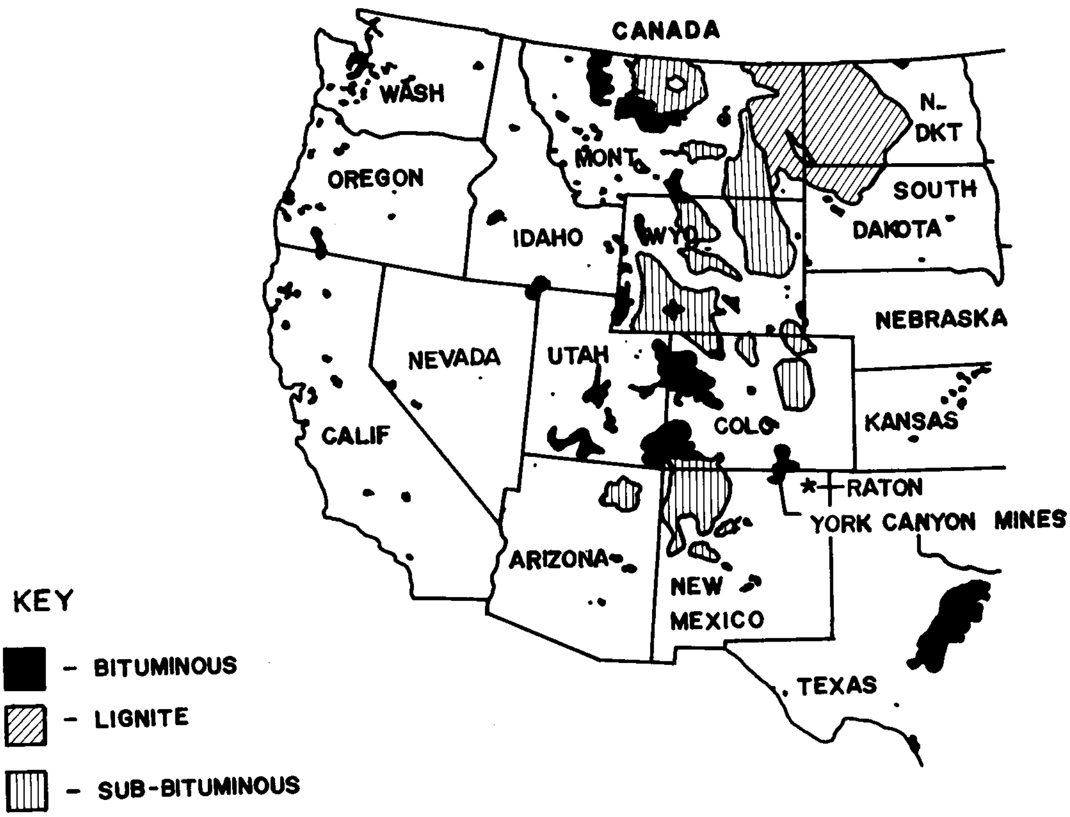
The York Canyon Surface and Underground Coal Mines, owned and operated by Kaiser Steel Corporation, are located in the Southern Rocky Mountains about 40 miles (64 km) west of Raton, New Mexico (Figure 1). The region is generally rugged and mountainous, highly dissected by many ephemeral/intermittent streams and arroyos. Elevations of the mine permit area range from 7,300 feet (2224 m) in the valley bottoms to 8,600 feet (2620 m) on the highest ridges.

The mine permit areas are found within the ponderosa pine vegetation zone. This zone is economically important because of its wide variety of resources and uses. Concomitantly it is one of the most difficult zones to manage because of the numerous interactions among users and user effects on the ecosystem as a whole. The historically important land uses of this zone are native cattle range and mining (Maker et al 1972). Other local and adjacent land uses encompass forestry, watershed, recreation, and wildlife, including hunting and fishing (Wolfe 1977).

Kaiser Steel Corporation owns coal reserves on over 160,000 acres (64,800 ha) in northeastern New Mexico. Thus, there is the potential for a number of additional underground mines as well as several more surface mines. With the enactment of recent legislation and bonding requirements, it has become imperative that mining companies determine the best, economical method of establishing a diverse, effective vegetative cover capable of succession.

FIGURE 1

THE YORK CANYON MINES ARE LOCATED IN THE RATON COAL FIELD ABOUT 40 MILES (64 KM) WEST OF RATON, NEW MEXICO



Use of introduced plant varieties in early reclamation efforts resulted in marginal success prompting a change to the utilization of primarily native species for revegetation. Initial positive results have been obtained in reclamation with an intensification of study, research, and planning.

CLIMATE

A cool, mountain climate predominates over the region. The average annual precipitation at the York Canyon Mine, based on a 5 year record, is 10.4 inches (26.4 cm). A study of monthly and seasonal precipitation records illustrates the primary season to be the summer months of June through August (Figure 2). Precipitation during this season falls primarily as high-intensity rain storms and comprises almost half of the average annual precipitation. Only 2.4% of the precipitation falls as light snow in winter. These dry snowfalls frequently sublimate. However, drifts may remain all winter on north facing slopes and in narrow valleys and canyons. The balance of the precipitation comes as rain which is nearly equally divided between the spring and fall seasons. Additional long term weather data is currently unavailable from the York Canyon area, but a complete weather station was recently installed at the mine site. Validity of interpolation from the closest long term records from Raton, New Mexico, is limited because of the mountainous terrain and localized weather patterns.

Wind records for one year at York Canyon indicate the average wind speed ranges from 6 mph to 8 mph, with the stronger average winds occurring in the spring and most of the gusty weather occurring in the fall.

The monthly average temperatures for 1980 are presented in Figure 3. The average maximum is 76.4°F (24.7°C) and the average minimum is 12°F (-11.1°C). The days are generally warm during the growing season but are countered by cool evenings; for example, in June 1980, the daily minimum is frequently less than half of the daily maximum. Evapotranspiration of the region is generally unknown. The Eagle Nest weather station 30 miles (48 km) to the southwest records 25 inches (63.5 cm) evaporation for the months of June, July and August.

GEOLOGY AND MINING

The mineable coals of the Raton coal field are found in the Upper Cretaceous Vermejo formation and in the Raton formation. The coal is a

FIGURE 2

AVERAGE MONTHLY PRECIPITATION AT THE YORK CANYON MINES, BASED ON A FIVE YEAR PERIOD

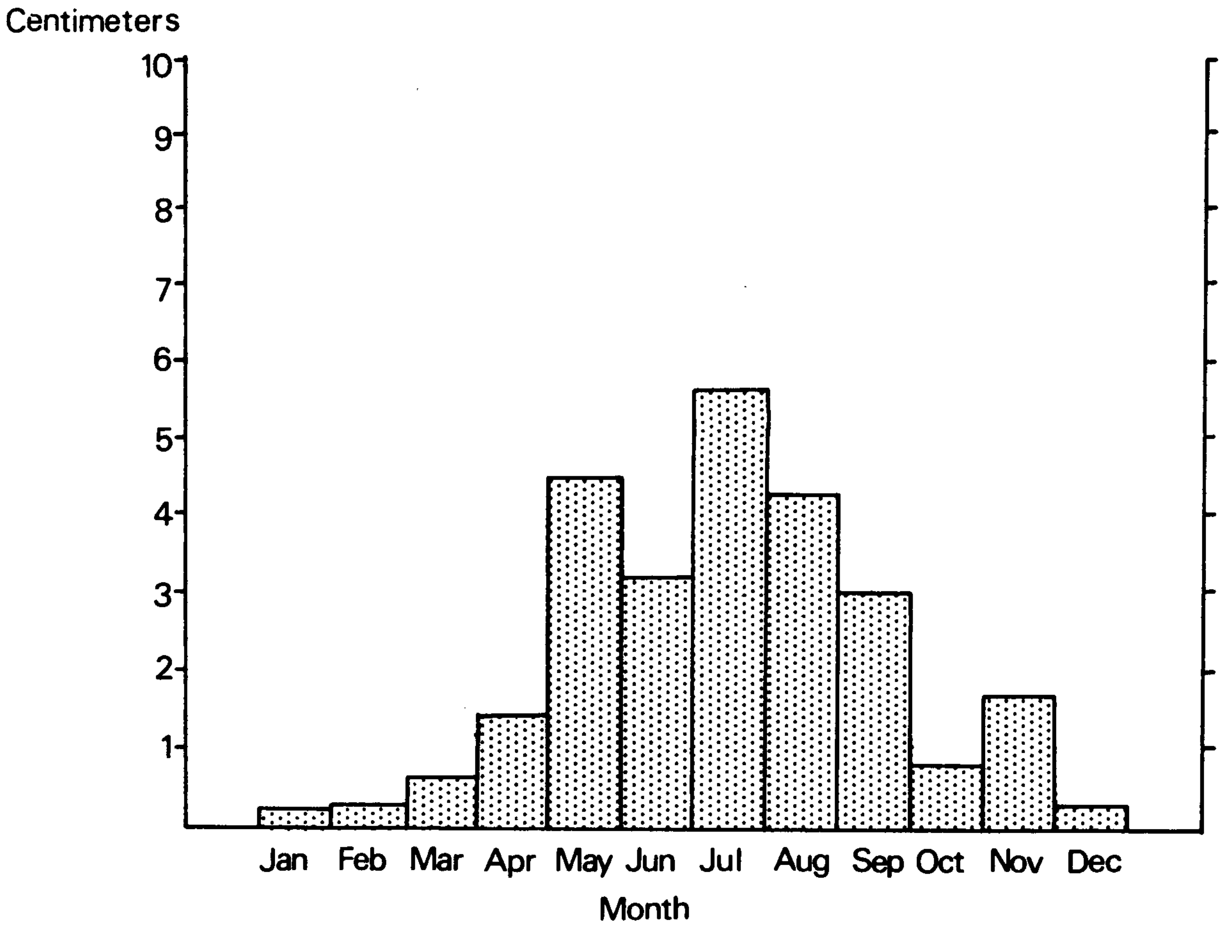
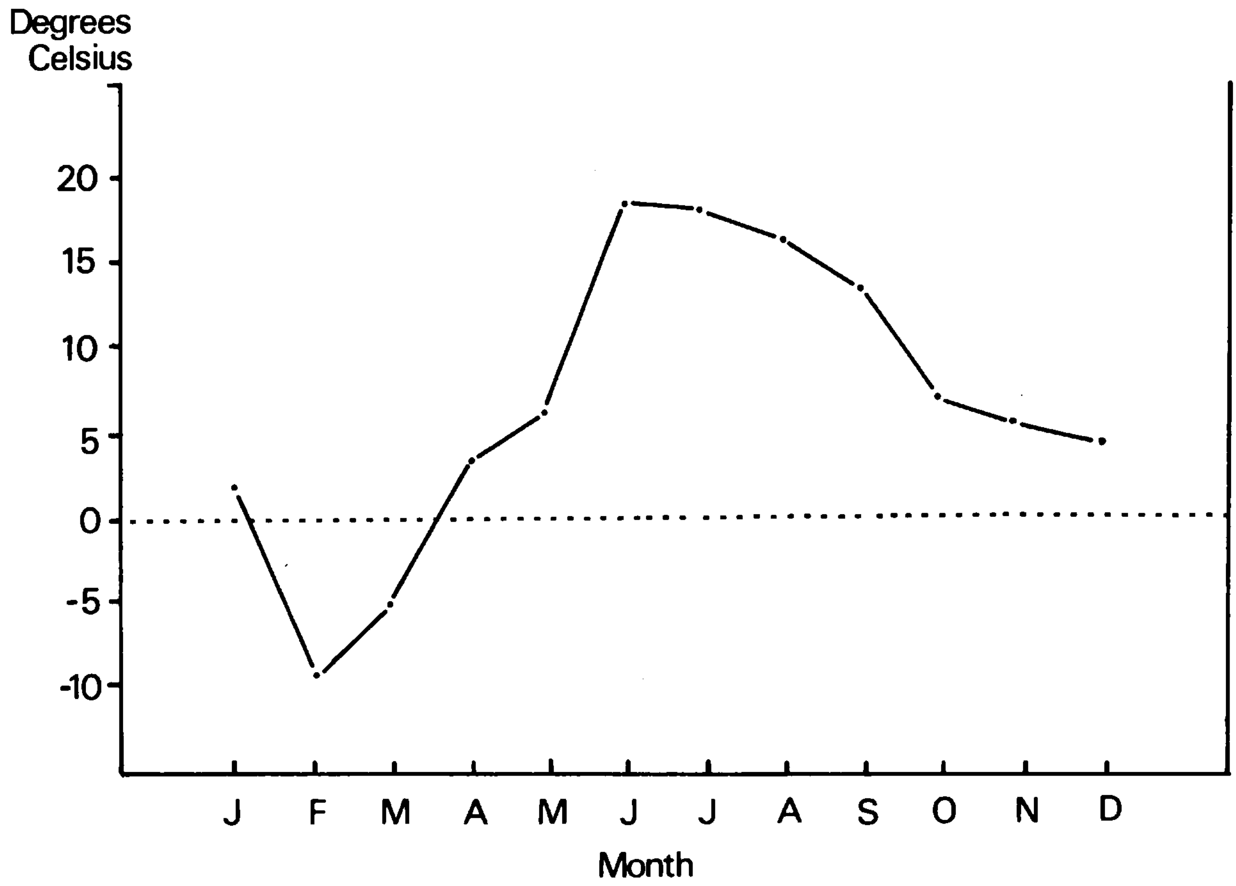


FIGURE 3

AVERAGE MONTHLY TEMPERATURE AT THE YORK CANYON MINES, NEW MEXICO, FROM A SINGLE YEAR'S DATA



high quality, low sulfur, bituminous product. The primary stratum being mined at York Canyon is the York Canyon seam which is found in the Raton formation of Late Cretaceous-Early Paleocene Age. It is located in the coal bearing strata approximately 1,100 feet (335 m) stratagraphically above the base of the Raton formation (Figure 4). The sediments exposed or found near the surface of the Raton Basin are shallow sea and continental alluvial deposits of Late Cretaceous and Tertiary Age. Pierre Shale forms the foundation of the plains east of the mines and is exposed to the west of the mines. It is found beneath the Trinidad Sandstone with which it is interbedded. Trinidad Sandstone is comprised of shallow water beach deposits of a Late Cretaceous Sea (Gill and Cobban 1969).

Coal mining began in York Canyon with the opening of the underground mine. About 800,000 tons (725,760 metric tons) of coal per year are produced by longwall and continuous miner. Coal from the underground mine is washed and used for metallurgical purposes. Surface coal mining began in 1972, with full production not beginning until 1978. Approximately 700,000 tons (680,400 metric tons) of coal per year are crushed and used for steam coal. The surface mine is a combination dragline/shovel/truck operation. Coal is removed primarily with the use of loaders and trucks or an Easi-miner.

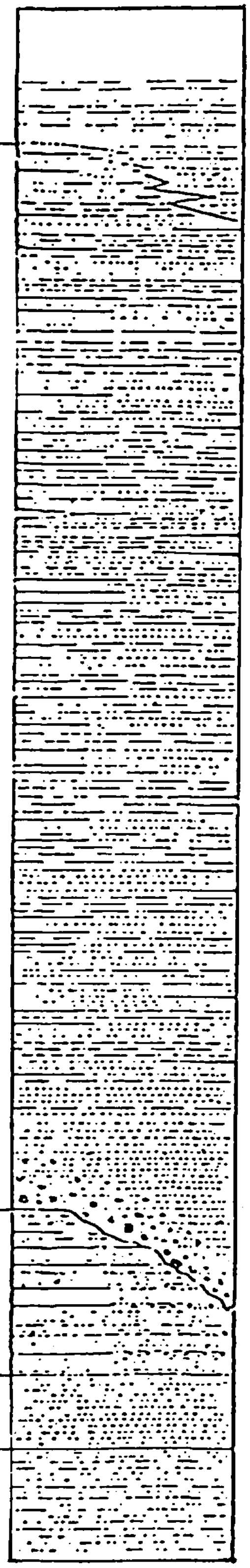
GOVERNMENT REGULATIONS

Since the adoption of the Surface Mining Control and Reclamation Act in 1977, the State of New Mexico has updated its State regulations to equal those of the federal government. This process has taken about three years. However, at the present time the federal regulations are being revised under the direction of President Reagan and most state governments intend to follow suit. This process will undoubtedly take several additional years, meanwhile creating uncertainty and complications for many mining companies. As some of the regulations pertaining to reclamation and revegetation are ecologically unsound, it is appropriate they are being rewritten. However, constant change in regulation presents problems in reclamation and permit planning, but that is a topic outside the realm of this discussion.

The general revegetation requirements for the State of New Mexico are as follows:

FIGURE 4

GENERALIZED LITHOLOGICAL SECTION ON THE RATON COAL PROPERTY

POISON CANYON FORMATION (sandstone with interbeds of sandy claystone)		
RATON FORMATION (sandstone interbedded with siltstone, claystone, mudstone, and beds of carbonaceous shale and coal)	Chimney Divide Coal Seam Numerous Unamed Coal Beds York Canyon Coal Seam Ancho Canyon Coal Seam Cottonwood Canyon Coal Seam Left Fork Coal Seams Potato Canyon Coal Seam Green Coal Seam Brown Coal Seam Numerous Unamed Coal Beds Unconformity	
VERMEJO FORMATION (sandstone, siltstone, silty carbonaceous shale and coal)	Vermejo Seam Raton Seam	
TRINIDAD SANDSTONE		
PIERRE SHALE		

70-111 Revegetation: General Requirements (B16.111 and B17.111)

a. Each person who conducts surface coal mining operations shall establish on all affected land a diverse, effective, and permanent vegetative cover of the same aspection native to the area of disturbed land or species that supports the approved postmining land use. For areas designated as prime farmland, the requirements of Part 24 shall apply.

b. All revegetation shall be in compliance with the plans submitted under Sections 9-18 and 9-23, as approved by the Director in the permit and carried out in a manner that encourages a prompt vegetative cover and recovery of productivity levels compatible with the approved postmining land use.

   1. All disturbed land, except water areas and surface areas of roads that are approved as part of the postmining land use, shall be seeded or planted to achieve a permanent vegetative cover of the same aspection native to the area of disturbed land.

   2. The vegetative cover shall be capable of stabilizing the soil surface from erosion.

   3. Vegetative cover shall be considered of the same aspection when it consists of a mixture of species of equal or superior utility for the approved postmining land use, when compared with the utility of naturally occurring vegetation during each season of the year.

   4. If both the premining and postmining land uses are crop land, the reclaimed land shall have the capability of meeting or exceeding the premining crop production.

RECLAMATION AND REVEGETATION PLANNING

The major problems and challenges Kaiser Steel Corporation has encountered in reclaiming mountainous terrain in the Southwest are: a complex postmine land use; steep slopes; thin, rocky, discontinuous topsoil; low annual precipitation; high intensity rainfall; uncertainty of available irrigation water; lack of published studies concerning plant succession (Wagner et al 1978); and the natural ecosystems in northeastern New Mexico. Kaiser Steel Corporation is attempting to eliminate these problems through planning, study of baseline data, monitoring of the environment, implementation of new reclamation techniques, record maintenance, and research.

There are four general phases of reclamation planning and management (Murdock 1980):

1. designation of postmine land use goals
2. baseline data accumulation
3. reclamation/revegetation
4. postmine management

POSTMINE LAND USE

One of the first decisions to be determined is that of a goal for postmine land use. In many instances this goal will determine how and what type of baseline data is collected. Land use is also of primary importance in determining the direction of reclamation and revegetation planning.

The proposed postmine land uses of the mines at York Canyon are fish and wildlife habitat and native rangeland as defined by the New Mexico State Surface Mining Regulations.* These uses constitute the historical and current land uses as well as being the primary land uses of the surrounding properties owned by Santa Fe Mining, Inc., Vermejo Park Corporation, and Kaiser Steel Corporation. Vermejo Park Corporation conducts hunting, fishing, and recreation on a commercial basis on over 479,000 acres (201,285 ha) surrounding the York Canyon Mines (Wolfe 1977).

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*Fish and Wildlife Habitat: Means land dedicated wholly or partially to the production, protection or management of species of fish or wildlife.

Rangeland: Means land on which the natural potential (climax) plant cover is principally native grasses, forbs and shrubs valuable for forage. Except for brush control, management is primarily achieved by regulating the intensity of grazing and season of use.

As the York Canyon Mines are a comparatively small property within the Vermejo Park Ranch and elk have large home ranges, the ranch wildlife management practices affect the big game animals which range throughout the mine properties (Jansen 1980).

Practicality and utility limit the possibility of alternative postmine land uses. Physiographically the reclaimed land would not be suited as crop or pastureland. The area is not accessible to flood irrigation and the general scarcity of water limits both the potential of a developed water resource and a residential development which is not compatible with surrounding land uses. Non-consumptive recreation is a possible alternative land use.

An analysis of postmine land use alternatives indicates that wildlife habitat and native rangeland are the most appropriate postmine land uses. But in terms of reclamation, land use should be even more critically evaluated. For example, as it is impractical and difficult to address all types of wildlife habitat in reclamation and revegetation, specific wildlife use should be postulated. Therefore, because of their economic importance (Wolfe 1980) elk and deer have been selected as the game species for which reclamation efforts are directed. The area is used by wildlife year-round and also serves as winter cattle range. This use pattern increases the necessity of revegetating with plants which can supply protein during the winter.

Multiple uses complicate planning. It must be realized that although cattle (Stoddart et al 1975) and elk (Murie 1951) are primarily grazers, they also consume many forbs and shrubs. For elk, however, forbs are only important in the summer. Gates (1967) reported a year-round diet for elk was comprised of 85% grass. Deer are primarily browzers (Taylor 1956), although they use grasses frequently in the spring and summer. Recent studies have found high quality summer range important for deer (Urness et al 1975). Protein and digestible energy are important for cattle (Cook et al 1977) as well as for deer and elk (Welch and Andrus 1977; Wallmo et al 1977). Others (Lay 1969, Zeedyk 1969) imply forage diversity to be the key to habitat quality while Clary and Larson (1971) found deer use patterns in the ponderosa pine habitat type to be random. Clary and Larson (1971) also found elk showed preference for areas with low timber basal area and high herbage yields. But use cannot be defined only in terms of forage. Habitat value is also important and is a function of food, cover, water, land form, and intarspersion (WELAT 1978). It is apparent, then, that designing a plan to fulfill postmine land uses becomes very complex.

BASELINE DATA ACCUMULATION

After a postmining land use has been chosen, baseline studies should be addressed. The following discussion pertains only to studies pertinent to reclamation and revegetation planning. Reclamation requires site-specific knowledge of the structure and function of the surrounding ecosystems (Wali 1980). Baseline information is necessary for planning revegetation, predicting potential reclamation success, and monitoring plant and animal succession. Baseline data in some format is also used for comparison to reclaimed sites or to set up a system for the determination of reclamation success.

The vegetation survey, normally one of the first studies to be instigated, was conducted at York Canyon during 1980. Each community was mapped; then statistically valid intensive sampling was completed. Slope and aspect were measured and each sampling site was correlated with soils. The plant cover in each community was measured. Density of trees and shrubs was determined as well as height, age and diameter of timber species. This information was used to determine timber volumes. All plant species were identified to characterize each community and to assure the presence or absence of any rare or endangered species. The vegetation data was analyzed to study the structure and development of each community. Community structure aids in the determination and mapping of habitat types. A habitat type (Daubenmire 1968) represents all the land areas which support, or are capable of supporting the same vegetation or plant association. This concept proves extremely useful in reclamation planning.

About 19 different plant communities have been delineated at the York Canyon Mines (Table 1). No doubt some represent seral communities. The species components and successional status become very important when considering what to include in the revegetation seed mixes.

The soils were also mapped and studied in conjunction with vegetation. The soils at York Canyon were formed from interbedded shales and sandstones as described by Pillmore (1976). As a result, the soils reflect very complex development (Sellnow 1979). Most of the mapping units of the first order survey consist of soil complexes. The soil series units

TABLE 1

VEGETATION TYPES AT THE YORK CANYON MINES, NEW MEXICO

Grassy bottoms, main valley	Agropyron smithii/Atriplex canescens
Grassy bottoms, side valley	Agropyron smithii/Bouteloua gracilis
Grassy top	Bouteloua gracilis/Festuca arizonica
Grass/winterfat	Bouteloua gracilis/Eurotia lanata
Riparian sedge meadow	Carex spp.
Riparian cottonwood grove	Populus angustifolia
Riparian willow patch	Salix spp.
Pinyon/juniper	Pinus edulis/Juniperus scopulorum, Juniperus monosperma
Pinyon-juniper/grass	Pinus edulis/Juniperus scopulorum, Bouteloua gracilis
Pinyon-juniper/oak	Pinus edulis/Juniperus scopulorum/Quercus undulata
Ponderosa pine	Pinus ponderosa
Ponderosa pine/oak	Pinus ponderosa/Quercus undulata
Ponderosa pine/Douglas fir	Pinus ponderosa/Pseudostuga menziesii
Mixed conifer	Pinus ponderosa/Pseudostuga menziesii/Pinus edulis
Ponderosa pine/pinyon-juniper/grass	Pinus ponderosa/P. edulis/J. scopulorum/ Bouteloua gracilis
Ponderosa pine/pinyon-juniper/oak	Pinus ponderosa/P. edulis/J. scepulerum/Quercus undulata

are so intricately mixed or small in area that they cannot practically be shown separately on a map. The soils typically contain numerous inclusions and rock outcrops (Table 2) which increase the difficulty of planning. Additionally, these intricate and rocky soils often occur on steep slopes, which makes complete removal difficult and unsafe.

All soils to be disturbed were sampled and chemically analyzed (Appendix 1) and no toxicities were found to occur. The soils generally tend toward textures of sandy clay or sandy clay loams with medium permeabilities. Similar analyses have been completed on overburden cores. No toxicities of heavy metals were noted, but some shales showed high SAR values. However, dilution of the overburden is expected to eliminate any salt problem.

Weather records are being developed and studied. Because of the variability in local and regional weather patterns, several remote precipitation gauges were also located within the permit area to determine the range of variability in the precipitation.

Surface water and ground water systems are also studied. Numerous monitoring wells or piezometers have been installed as well as crest stage gauges and surface water quality sample locations have been established above and below the mine sites on the major drainages. Study of the groundwater has failed to identify any groundwater aquifers as defined by the Surface Coal Mining Regulations; however, alluvial aquifers are present. Water monitoring is to continue throughout the life of the mine, to assure mining does not deteriorate water quality and to show reclamation maintains sediment from reclaimed sites in quantities similar to those from unmined areas.

After consultation with the New Mexico State Game and Fish Department wildlife studies were instigated. In 1979, a study of the movements of deer and elk in relation to mining activity was begun in cooperation with the research established at the Vermejo Park Ranch (Wolfe 1980). Kaiser Steel Corporation personnel have placed a number of cloth identification collars and radio transmitting collars on both deer and elk and trace their movements with the use of radio telemetry. Preliminary data indicate that elk have such large home ranges that their movements are unaffected by the present mining operation; however, other types of impact may occur. Deer have also apparently acclimatized to the disturbance. Collared animals of both sexes spend their life year-

TABLE 2

CHARACTERISTICS OF SOILS OVER THE COAL SEAM AT THE YORK CANYON SURFACE MINE

SOIL MAPPING UNIT		TOTAL ACRES/ SOILS UNIT	INCLUDED SOILS		KNOWN ROCK OUTCROP		SCATTERED ROCK OUTCROP PRESENT
SYMBOL	NAME		%	ACRES	%	ACRES	
7	Brycan loam	5.96	20	1.19			
8	Brycan loam	27.12	20	5.42			
9	Brycan loam	50.55	25	12.64			
18	Fuera complex	62.84	20	12.56	50% of inclusions	6.28	
27	Midnight-Stout	45.13	25	11.28			YES
28	Midnight-Ponil	38.09	25	9.52			YES
30	Ponil complex	16.55	15	2.48			YES
31	Ponil-Rombo complex	18.95	20	3.79	50% of inclusions	1.89	
32	Ponil-Rombo complex	46.75	20	9.35	50% of inclusions	4.67	
33	Ponil complex	26.97	20	5.39			YES
35	Rombo complex	7.65	15	1.14			YES
37	Rombo-Ponil complex	69.51	20	13.90	50% of inclusions	6.95	
38	Rombo-Rock outcrop	245.13	20	49.026	35% of Unit	85.79	
39	Rombo-Rock outcrop	24.57	20	4.9	40% of Unit	9.82	
40	Stout-Rock outcrop	2.03	15	0.3	30% of Unit	0.61	
41	Stout-Rock outcrop	38.59	15	5.78	30% of Unit	11.57	
42	Stout-Rock outcrop	34.72	15	5.2	40% of Unit	13.88	
43	Stout-Rock outcrop	52.16	20	10.43	40% of Unit	20.86	
48	Vamer-Stout complex	36.17	20	7.23			YES
50	Sandstone-Rock complex	1.16	10	0.11	90% of Unit	1.05	
				171.63		163.37	

The acreages shown are as planimetered and are believed accurate to ± 5%.

round within the permit areas (Jansen 1981). Collared does have been producing healthy twin fawns which indicates they are not under a nutritional (Robinette 1956) or reproductive stress. Additionally, seasonal bird surveys are conducted and daily wildlife checklists are maintained of all wildlife observations.

RECLAMATION/REVEGETATION

Our methods and knowledge of reclamation and revegetation are currently in the evolutionary process. Information gleaned from baseline studies of the adjacent ecosystems and research is integrated in the formulation of the reclamation plan. Study of these ecosystems can be the key to successful reclamation.

Reclamation should be considered as an integral part of the mining operation, both in planning and during production, but this is not always an easy situation to establish. In attempts to find answers to reclamation problems many researchers and biologists have failed to develop solutions practicable to the everyday mining situation. This failure has created skepticism concerning some reclamation methods among many engineers and mine managements.

Reclamation must work within the framework of the mine plan. The combination shovel/truck/dragline operation at York Canyon dictates a delayed revegetation procedure as shovel/truck overburden is placed upon graded dragline spoils. Initially, the land is cleared and topsoil which has been removed after clearing must be stockpiled. Nevertheless, reclamation is contemporaneous to this particular method of mining.

The first major step in reclamation after overburden placement is backfilling and grading. Because of the rugged mountainous nature of the landscape at York Canyon, grading recreated some steep slopes. Study of the natural physiognomy was used as a guideline for slope reconstruction and problem solving.

Of the 20 soil types overlying the coal outcrop at the York Canyon Surface Mine, six contain scattered rock outcrop, four contain 10% rock outcrop, two contain 30% rock outcrop, three contain 40% rock outcrop, and one contains 90% rock outcrop (Sellnow 1979). Topographic variation can be a positive by-product of surface mining in that specific habitat types can be recreated.

Reconnaissance surveys of premined areas indicate that the following plant communities are characteristic of rocky habitats: oak, mixed shrub, pinyon-juniper, pinyon-juniper/oak, pinyon-juniper/grass. In fact, many of the species found within these communities grow exclusively in rock outcrop areas or on thin rocky soils at York Canyon. These plants are apparently unable to compete in deep soiled areas (Wolfe et al 1980) (Table 3).

Outcrops and escarpments created by leaving sections of highwall intact are often the only areas where some raptors can nest and rear young without frequent harassment (Klimstra et al 1979). Such raptors endemic to the York Canyon Mine area include the prairie falcon *(Falco mexicanus)*, American Kestrel *(Falco sparverius)*, pigeon hawk *(Falco columbarius)*, and the great horned owl *(Bubo virginianus)*. The red-tailed hawk *(Buteo jamaicensis)*, and the marsh hawk *(Circus cyaneus)* utilize outcrops around the mine site as hunting perches (Wolfe 1978 personal observation). Rocky areas also provide nest and cover sites for the following avian species common to the area: cliff swallow *(Petrochelidon pyrrhonota)*, violet-green swallow *(Tachycineta thalassina)*, common raven *(Corvus corax)*, pinyon jay *(Gymnorhinus cyanocephala)*, rock wren *(Calpinctes obsoletus)*, canyon wren *(Catherpes mexicanus)*, common bushtit *(Psaltriparus minimus)*, and Townsend's solitaire *(Myadestes townsendi)* (Peterson 1961).

The shrub species most important to big game for browse and cover are among those plants typical of rocky areas. It is of concern that without sufficient shrubs for cover and browse, the postmine land will be unable to continue support of present mule deer *(Odocoileus hemionus)* and elk *(Cervus elaphus nelsoni)* populations.

Other wildlife species endemic to the mine site which utilize habitat types found exclusively in rocky areas include: gray fox *(Urocyon cineroargenteus)*, bobcat *(Lynx rufus)*, coyote *(Canis latrans)*, weasel *(Mustela erminea, M. frenata)*, skunks *(Mephitis mephitis, Conepatus leuconotus)*, badger *(Taxidea taxus)*, rock squirrel *(Citellus variegatus)*, Mexican woodrat *(Neotoma mexicana)*, deer mouse *(Peromyscus maniculatus)*, rock mouse *(Peromyscus difficilis)*, Colorado chipmunk *(Eutamias quadrivittatus)*, mountain lion *(Felis concolor)*, black bear *(Ursus americanus)*, (Patton, 1978), and Merriam's turkey *(Meleagris gallopavo)*. Frischtenecht (1975) summarized literature indicating the use of rock areas by numerous insectivorus and cannibalistic lizards, horned lizards, and snakes, including the prairie rattler *(Crotalus*

TABLE 3

PLANT SPECIES CHARACTERISTIC OF ROCKY AREAS

Common Name	Scientific Name
Big bluestem	Andropogon gerardi
Little bluestem	A. scoparius
Fourwing saltbush	Atriplex canescens
Sideoats grama	Bouteloua curtependula
Mountain mahogany	Cercocarpus montanus
Hedgehog cactus	Echinocereus spp.
Eriogonom	Eriogonum spp.
Cliff jamesia	Jamesia americana
One-seeded juniper	Juniperus monosperma
Rocky Mountain juniper	Juniperus scopulorum
Colorado four-o-clock	Mirabilis multiflora
Penstemon	Penstemon barbatus torreyi
Pinyon	Pinus edulis
Gambel oak	Quercus gambelii
Wavey leaf oak	Quercus undulata
Skunkbush sumac	Rhus trilobata
Scribner's needlegrass	Stipa scribneri
Yucca	Yucca glauca/Yucca baccata

3

viridis viridis) and western diamondback *(Crotalus atrox),* all common at the mine site.

Leaving rock outcrops within portions of the highwall and at other locations is not only essential for the re-establishment of the many plant communities which occur naturally on the mine site as well as for the wildlife which depend on them, but also reduces reclamation cost through a reduction of regrading requirements.

To these ends a highwall plan was considered ecologically appropriate and economically feasible. Figure 5 illustrates a previously existing portion of the highwall. A plan was designed to simulate pre-mine landscape and habitat types by allowing portions of the upper parts of the highwall comprised of horizontal sandstone bedding to remain as rock outcrops and talus areas. The highwall retention plan was instigated where it appeared appropriate.

Figure 6 shows a diagrammatic sketch of the final configuration of a portion of the site. The vertical bedrock blends well with the rocky terrain of the hillside. Bedrock is exposed in numerous areas above the highwall and the rock outcrop blends into the bedrock in two locations. The approximate height of the outcrop varies from 2 feet to 23 feet. The outcrop is almost continuous and is approximately 220 feet long. It has a vertical face, but the rock surfaces tend to be rounded, although there are also a few angular surfaces.

The ground surface at the base of the outcrop is rocky. This increases infiltration, lessens raindrop impact and slows the velocity of runoff. Talus was used to blend the highwall with the surrounding landscape.

The outcrops are not expected to become unstable outside of a long term geological sense. When the geologic structure consists of horizontal bedding with vertical to subvertical jointing, the possibility of a failure is essentially eliminated, therefore the static safety factor would be far greater than 1.5 (Dames and Moore 1978). The bedrock outcrop, therefore, would be very stable.

Those areas which are left as talus slopes or simulated rock outcrops also reflect a static safety factor much greater than 1.5. In fact, an analysis of a typical situation predicts that the rocks would have a static safety factor of 8 (see calculations in Appendix 2). This number

FIGURE 5

PART OF THE CENTRAL AREA HIGHWALL AFTER MINING AND PRIOR TO RECLAMATION

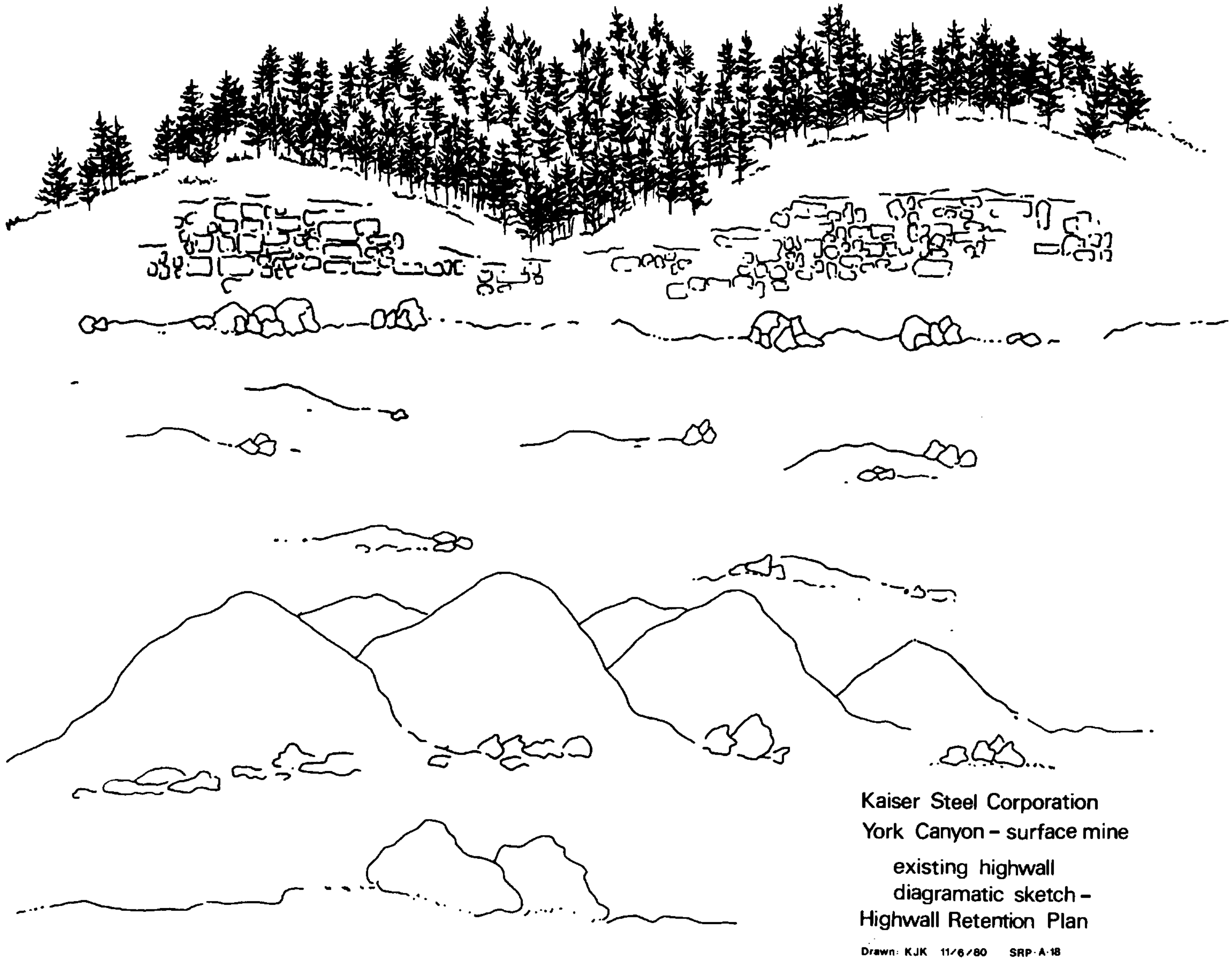
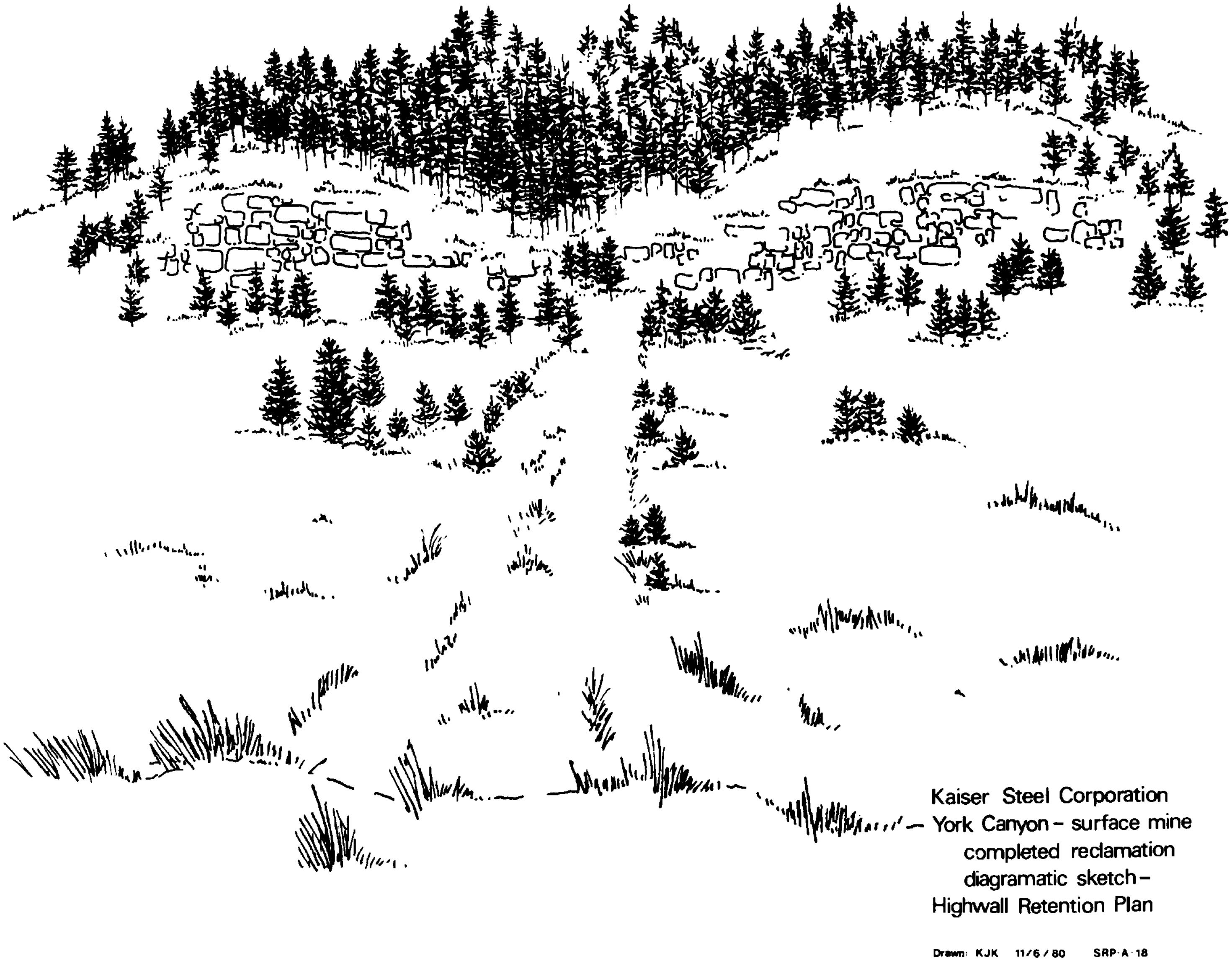


FIGURE 6

SKETCH OF THE COMPLETED RECLAMATION OF THE CENTRAL AREA HIGHWALL



indicates that the talus is extremely stable. Therefore, these rocky slopes do not represent any greater potential danger to humans or wildlife than do natural outcrop areas.

Rock piles have also been selectively placed on portions of the reclaimed site for habitat diversity and wildlife cover, as it would take trees years to provide similar hiding areas. These rock piles also act as windbreaks and ameliorate the immediate environment in terms of temperature and moisture (Harju 1980). The rock piles are large in size because elk and deer require cover capable of blocking 90% of the animals from human view at a distance equal to or less than 200 feet (61 m) (Thomas et al 1979).

Reclamation plans also include placement of fallen logs on reclaimed sites. Pinyon jays prefer to stash seeds next to rocks and fallen logs (Ligon 1978). Downed logs are excellent hiding cover for smaller forms of wildlife. Again they may act as snow harvesting devices and further ameliorate the immediate environment. After the second year of establishment it is also planned to install posts as perches for birds which hunt rodents.

A certain amount of landscaping is necessary to design steep slopes to blend with the surrounding undisturbed area. Additionally, except for specially designed drainages, the hillsides should be sloped such that water will not accumulate at any one point. Thus, natural water spreading is created, benefitting vegetation establishment and minimizing erosion.

Rough bed channels similar to those invented by Lorenz (Schiechtl 1980) are planned for drainages. These drainages closely simulate those I have observed in the forested slopes of the mine permit area. In these channels water flows over large sandstone rocks wedged tightly against each other, which minimizes soil erosion.

After grading, stockpiled topsoil is redistributed on the slopes. At York Canyon, the soils removed prior to mining usually represented the A and B horizons. The rocky character of the topsoil (Table 2) proved to be serendipitous, helping to minimize a number of reclamation problems. A one inch (2.5 cm) layer of rock can act as a mulch and is an excellent method of erosion control (Kay 1978). The baseline vegetation data also indicated ground covers of rock on undisturbed sites ranged from 5% to 30% (Wolfe et al 1980).

Intuitively, the rock present in the soil also acts as a water harvesting mechanism. Evans and Young (1972) found conditions in soil depressions more conducive to seed germination. Thus, by redistributing rocky topsoil on steep slopes, erosion can be minimized and germination enhanced when precipitation is low and irrigation water availability uncertain (Harthill and McKell 1979). This procedure appears to be successful at York Canyon.

Because the topsoil is thin, discing prior to seeding is used to improve infiltration and plant growth. Ripping would gouge large boulders of overburden to the surface.

The goal of the revegetation plan is to plant once and successfully establish a seral plant community capable of self-replication, succession and able to support the postmine land uses.

Until an irrigation regime for plant establishment can be developed, major plantings are done in May and June, prior to the months of major precipitation. The general schedule for revegetation is shown in Table 4. June is a relatively dry month which could kill young seedlings planted in April or May. The last frost can also occur during these months, as late as the first week in June.

Experimentation with fall seeding has failed. Less than 3% of the annual precipitation comes in winter and there is little, if any, protective snow cover. Apparently, seed predation and seed mortality are too high for sufficient germination to produce an effective vegetation cover capable of erosion control.

Prior to planting, and after soil analyses, the postmine contours are mapped according to potential habitat type. This facilitates selection of seed mixes to be planted for a specific area and the location of future tree and shrub plantings.

It is virtually impossible to replace all plant species because of lack of seed availability, economics, practicality, and efficiency. Seed mixtures used have been designed to include large proportions of some species, primarily grasses which are relatively economical and capable of providing quick, effective vegetative cover to control erosion and provide a base for initiating succession. Small amounts of forb and shrub seeds have been added to the mixtures to provide additional diversity.

TABLE 4

GENERAL REVEGETATION SCHEDULE

Procedure	Weeks in Month*						
	March	April	May	June	July	August	Sept.	Oct.
Transplant	3,4	1,2,3,4	1,2					
Replace Topsoil	1,2,3,4	1,2,3,4	1,2,3,4	1,2				
Disc		2,3,4	1,2,3,4	1,2,3,4				
Fertilize		3,4	1,2					
Seed		4	1,2,3,4	1,2,3,4	1,2			
Mulch			1,2,3,4	1,2,3,4	1,2			
Tack			1,2,3,4	1,2,3,4	1,2			
Irrigate				2,3,4,4	1,2,3,4	1,2,3,4		
Fertilize							1,2,3,4	1,2

*1 designates first week of the month;
2 designates second week of the month, etc.

All seed species selected for revegetation presently occur at the mine site and most are found to be valuable for supporting the postmine land use of native rangeland for deer, elk, and cattle. They have been derived from existing plant communities and various literature sources. Commercial sources have been obtained from the Cross Reference Nursery Index of Native Plant Species (Wolfe 1979). They consist of both warm and cool season perennials.

Presently the seed mixtures contain only two "introduced" species, Kentucky bluegrass *(Poa pratensis)* and redtop *(Agrostis alba)*. These species are widely naturalized in the United States (USFS 1937) and are components of the present vegetation in York Canyon. They are good forage for horses, cattle, sheep, and elk. Kentucky bluegrass is one of the better forages for deer (USFS 1937), as it withstands heavy grazing pressure well and is valuable as a soil stabilizer (Gay and Dywer 1970). Although *A. alba* is probably an introduced species (Hitchcock et al 1969), Boivin and Love (in Hitchcock 1969) contend *P. pratensis* is native to the United States.

Undisturbed vegetation at high elevations similar to the mine site normally contain very few annuals. The majority of annuals that are present in the pre-mine vegetation are weedy increaser species. These will not be seeded, since they are amply self-perpetuating. Furthermore, most of these native annuals are commercially unavailable.

Choosing forage species compatible for big game use may be of greater importance than formerly thought. Although mining regulations stress importance of creating high productivity, Devlin and George (1979) found elk forage utilization was not constantly proportional to plant productivity, but was related to physiological need and succulence of the vegetation. Nearly every species of tree, shrub, grass, or forb provides some type of nesting, escape, cover, or food value to wildlife. Known forage values of major revegetation species used are presented in Appendix 3 (Gay and Dywer 1970, Kufeld et al 1973, and USDA 1937).

Three different seed mixtures have been developed to establish a diverse, effective cover of vegetation (Tables 5 and 6). These seed mixtures form the basis for seeding several different habitat types. The bottomland mix was designed for all mesic valley floors. The slopes mix was selected for all hillsides, regardless of aspect, and the flats

TABLE 5

SEED MIXTURES - GRASSES

Plant Species	Percent in Bottoms Mix	Percent in Slopes Mix	Percent in Flats Mix
Agrostis alba	T		
Andropogon gerardi	T	4	
Andropogon scoparius	T	25	5
Agropyron smithii	25	5	20
Agropyron trachycaulum	5	1	
Bouteloua curtipendula	10	24	5
Bouteloua gracilis	40	30	4/24
Bouteloua hirsuta		1	1
Bromus marginatus		2	5
Festuca arizonica	T*	T	25/5
Hilaria jamesii	T	1	
Koeleria cristata	T	T	T
Muhlenbergia wrightii	5	2	
Panicum obtusum	T	2	10
Poa pratensis	T		
Sporobolus airoides	15		
Sporobolus cryptandrus			T
Stipa comata	T	1	5

*T = Trace Amount

TABLE 6

SEED MIXTURES - FORBS AND SHRUBS

Plant Species	Percent in Bottoms Mix	Percent in Slopes Mix	Percent in Flats Mix
Achillea lanulosa	-	T*	T
Artemisia frigida	T	T	T
Artemisia ludoviciana	-	T	T
Atriplex canescens	T	T	-
Chrysothamnus nauseosus	T	-	-
Clematis hirsutissima	T	T	T
Eurotia lanata	T	T	T
Liatris punctata	-	T	T
Limon lewisii	T	T	T
Mirabalis multiflora	-	T	-
Penstemon barbatus	T	T	T
Penstemon strictus	T	T	T
Penstemon whippleanus	-	T	T
Petalostemon purpureum	T	T	T
Ratibida columnifera	T	-	T
Rhus trilobata	-	T	-
Sphaeralcea coccinea	T	T	T
Yucca baccata	-	T	-

*T = Trace Amount

mix was developed for flat to gently rolling areas on hilltops and mesas. The percent of Arizona fescue *(F. arizonica)* and blue grama *(B. gracilis)* was appropriately altered to make one dominant, depending on the elevation and whether the habitat type to be planted was associated with ponderosa pine or pinyon/juniper. Experience in recent revegetation at York Canyon has indicated employment of three different mixtures to be successful. Species in the mixes best suited to the various microenvironments within each site are those which initially dominate the habitat type.

The seed mixtures will vary from year to year depending upon seed availability and the development of new species. Research concerning the adaptability of native species is currently ongoing at the mine site in cooperation with the U.S. Soil Conservation Service Plant Material Center in Los Lunas, New Mexico (Oaks 1980) and the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station in Albuquerque, New Mexico (Aldon et al 1979). Kaiser Steel Corporation has also begun its own work in the collecting and development of seed sources for wolftail *(Lycurus phleoides)*, mountain muhly *(Muhlenbergia montana)*, and white prairie clover *(Petalostemon candidum)* and in planting trees and shrubs.

Site-specific soil tests indicate small amounts of phosphorous need to be added to all areas at York Canyon prior to planting. Phosphorous is frequently important for germination and establishment (Berg 1978). This nutrient is spread during site preparation and is disced into the soil when possible. Heretofore, phosphorous has been applied at a rate of 30 lbs./acre P_2O_5 (34 kg/ha).

Any nitrogen fertilization is delayed until the beginning of the second growing season following seeding. This minimizes the establishment of annual weeds. Between 80 to 100 lbs./acre of NH_4NO_3 (90 to 112 kg/ha) is applied according to recommendations indicated by soil tests. Nitrogen maintenance will be applied only for establishment and application amounts will be kept to a minimum whenever possible as Sindelar (1980) has found nitrogen reduces species variety. Considering the current controversy concerning fertilizing, study concerning the use of fertilizers is planned. Studies have shown fertilizing of native range to increase productivity (Dwyer and Schickendanz 1971). Abbott (1981) has found phosphorous and nitrogen improved germination of native species on tailings in southern Colorado.

The following three methods are used in revegetation: drilling, broadcasting, and transplanting. When drilling, two times the normal rate is used. Three times the normal rate is used when broadcasting. These rates are based upon those recommended for critical areas (Merkle and Herbel 1973, EPA 1975). It is best to drill seed because of the proven higher rate of success in southwestern climates (Vallentine 1977, Merkle and Herbel 1973), even though results are often considered less aesthetic. Interseeding lightly with the hydroseeder can improve that aspect. A Truax Native Seed Drill is used for seeding flat areas and gentle slopes. This drill is especially designed for planting native species. For that purpose it has two different sized seed boxes with agitators. A hydroseeder is used on slopes too small or too steep for the drill. The seed is dispensed only with water as ground contact is essential for establishment in arid regions.

Establishment of trees and shrubs from seed takes many years in the arid southwest. Transplanting tree and shrub seedlings as well as larger trees provides a more immediate seed source to the area (Frizzell et al 1980). Transplanting also hastens succession by ameliorating the local environment and draws birds and animals to the site, thus augmenting seed dispersal.

Transplanting may either be of containerized nursery stock or clumps of native materials acquired on site by front end loaders or other means. Transplanting has proven difficult at York Canyon. Transplanting is normally completed during the early spring or late fall when trees and shrubs are dormant. Because of the long dry period after fall planting in this area, spring planting has shown the highest survival rates.

To date, best success has been obtained by transplanting native stock with a front end loader. Experimentation with planting tree seedlings in the summer and using a drip irrigation system is currently being conducted under the direction of Dr. James Fisher of New Mexico State University. In 1980, Kaiser Steel Corporation initiated field trials testing irrigation and a big game repellent on transplanted tree and shrub seedlings, but evaluation is not complete. Initial observations indicate success with conifers to be poor. Additional research on this subject is planned for the immediate future.

As wildlife is also a land use of this native range, placement and interspersion of various lifeforms must also be considered. Deer apparently have four preferred habitat types at York Canyon: pinyon-juniper, ponderosa pine, ponderosa pine/pinyon-juniper, and pinyon-juniper/oak. These communities all represent struotural complexities, created by layers of forbs, grasses, shrubs, and trees (Jansen 1981). It is best to plant trees and shrubs in such a manner as to create a good edge effect by placing groups with irregular boundaries (Thomas et al 1979).

All seeded areas were mulched to reduce erosion, increase germination, improve ground moisture and reduce surface soil temperatures. The primary method used was an application of native hay, normally applied with a blower at the rate of about two tons/acre (4.8 metric tons/ha). The hay was either crimped or sprayed with wood fiber and Terra Tac II* or both. Terra Tac II is a semi-refined seaweed extract. The rates used are those recommended by Terra Tac: a slurry of 2,500 gallons of water, three cases of Terra Tac and 9 bales of wood fiber for three acres. For slopes greater than 3:1 the mixture can be increased.

Terra Tac was found by Kay (1968) to be one of the best tackifiers on straw when compared to 11 other treatments and it also increased seed germination. Wood fiber or straw alone has not been sufficient at York Canyon to both enhance germination and control erosion. Studies at the mine site by the U.S. Forest Service indicated all methods of seeding were enhanced when a straw mulch was used (Aldon et al 1979). Furrows were also tested on slopes. Although seed establishment along furrows was improved compared to a control site (Aldon et al 1979), the furrows have caused serious erosion problems. Intense summer rains fill the furrows, causing them to burst, creating gullies. Rodent burrows also may cause the banks to fail. Furrowing also created contamination of the topsoil with overburden.

In the spring of 1981, an area mulched with two tons hay per acre was compared to one receiving a complete treatment of two tons hay, wood

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*Registered Trademark of Grass Growers, 424 Cottage Place, Plainfield, N.J. 07060.

fiber, and Terra Tac II. The areas were both characterized by southeast facing slopes and gentle sloping ridgetops. The sites were judged to be potential pinyon-juniper/oak habitat types which have an average herbaceous ground cover of about 12%. The complete mulch treatment established a 10 times greater vegetation cover, had 800% less bare ground and 2.6 times greater litter cover. Rock cover was similar in both cases (Table 7).

The hay/wood/fiber Terra Tac II mulch has proven capable of eliminating rill and gully formation on slopes up to 37% and establishing an initial vegetation cover without irrigation. Although relatively expensive, the intensive treatment enhanced vegetation growth and ultimately resulted in cost savings from reduction in erosion repair.

Observations over two years of sites planted with the techniques described herein indicate the methods to be successful. Cover of three sites planted in 1979 were randomly sampled by belt transects in the fall of 1980. Of the grasses seeded (Table 5), all the major species were established. Two seeded forbs were also established as well as fourwing saltbush. Surprisingly 22 other forbs and a half-shrub were also established. Of these, 25% were perennials. The many annuals were primarily native pioneer species, although *Kochia scoparia* was abundant. In terms of species number, species diversity rivaled that of most adjacent unmined habitat types. Species diversity of areas seeded with native plants was twice that of areas formerly seeded with introduced species. Ground cover sufficient to prevent the formation of rills and gullies was also established (Table 8) and was greater than that found in unmined pinyon-juniper/oak habitat types.

Conclusive evidence concerning the success of reclamation methods must be developed from long term data. However, preliminary conclusions drawn from observations over two years indicate these reclamation methods to be successful at York Canyon.

The need for applied research is apparent. Problems still exist in the establishment of trees and shrubs. Reclamation techniques for vegetation establishment on the coal refuse and tailings from the underground mine preparation plant need to be developed. Irrigation for plant establishment should also be tested as it could become necessary to irrigate should precipitation fall below the annual average.

TABLE 7

COMPARISON OF MULCH TREATMENTS

I. HAY ONLY				II. HAY WITH TERRA TAC AND WOOD FIBER			
	22% Slope	Flat	Average		22% Slope	Flat	Average
Vegetative Cover	.72	.33	.5	Vegetative Cover	4.15	5.8	4.98
Rock	4.4	2.9	3.63	Rock	3.7	.55	2.10
Bare Ground	66.1	62.3	64.2	Bare Ground	8.18	7.15	7.7
Litter	28.7	34.6	31.66	Litter	83.87	84.2	8.40

TABLE 8

INITIAL GROUNDWATER OF THREE RECLAIMED SITES

	79-1	79-2	79-3
Bare Ground	5.8	6.0	15.5
Rock	2.0	3.25	3.0
Litter	69.7	69.3	52.5
Vegetative Cover	22.6	21.4	29.9

POSTMINE MANAGEMENT

A record is maintained of each site which is planted. This record delineates the seed mix used, date seeded, planting methods, fertilizer used, results of soil analyses etc. and any other treatment a site has received. If a failure occurs, an analysis of the record may reveal potential reasons, and adjustments to future reclamation plans can be designed.

At this point neither small mammals nor weeds have developed into a management problem. Rabbit and other rodent signs on the reclaimed sites are recorded. Personal observation has also shown these areas are frequented and hunted by such predators as the coyote, red tailed hawks, marsh hawks, and the American Kestrel.

No livestock grazing will be allowed on the reclaimed sites until bond release, unless it is used experimentally at a later date. There is some evidence that the Savory short duration grazing method enhances plant succession (Allen Savory, personal communication). A method such as this may prove useful for future reclamation management.

Pellet transects have been installed on the reclaimed areas to monitor seasonal trends of deer and elk use. Pellet group counting is the process of estimating by fecal pellet group counts and the actual or relative numbers of big game animals or their number of days use in a given area. Although various difficulties are involved with pellet group counts, this method has the distinct advantage of having an inert kind of evidence which can be subjected to field plot sampling and statistical analysis (Neff 1968).

Big game movement studies are ongoing during the mining operation and data review is on a biennial basis. Monitoring is necessary to determine if deer and elk establish use patterns on the reclaimed sites to be expected of areas in a similar state of succession. Some small mammal trapping is planned to trace succession and development of species diversity. Population trends will be monitored to avoid detrimental impact on the reclaimed areas.

Annual vegetation sampling is conducted on each reclaimed site. Comprehensive species lists are accumulated in addition to ground cover data.

Permanent photo points have been set up around the mine site. Soil samples are also taken on each site to document successive changes in the chemical constituents.

After reclamation efforts have been successfully completed and bond is released, it will be up to the individual land owners to implement and maintain good management practices on the reclaimed lands.

CONCLUSION

Initial reclamation efforts by Kaiser Steel Corporation in the mountains of northeastern New Mexico have been successful. Achieving reclamation goals for the postmine land uses of wildlife habitat and cattle grazing on native rangeland is a complex and challenging process. Study of surrounding ecosystems and their components can provide clues for solving many reclamation problems and can aid in creating a landscape better suited for the postmining land uses, such as the use of partial highwalls, talus, rock piles and bird perches.

Utilization of rocky soil on steep slopes and a high profile mulch used with tackifiers can prevent erosion and enhance germination of native species under an average precipitation regime of 10 inches (26.4 cm). Continued analyses of adjacent ecosystems, wildlife monitoring, and careful record of succession on reclaimed sites are being used to evaluate and improve reclamation technology in the mountains of the southwest.

ACKNOWLEDGEMENTS

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APPENDIX 1

APPENDIX 1
CHEMICAL CHARACTERISTICS OF PRE-MINE SOILS

Soil	Depth "	pH	ec	OM	ppm N	ppm P	ppm K	ppm Zn	ppm Fe	Lime	ppm Mn	ppm Cu	SAR	ppm Se	ppm As	ppm Mo	ppm Cd	ppm Pb	ppm Ni	ppm Cr	Textures
Brycan loam	0-4	7.5	.6	3.0	9	1	322	.66	8.7	LO	1.81	1.78	.7	.45	3.1	L3	L2	38	15	30	Sandy clay
Brycan loam	4-66	7.5	.9	3.3	42	1	181	1.19	9.8	LO	2.97	2.62	.7	.32	3.4	L3	L2	35	16	35	Loam
Brycan loam	0-4	6.3	.4	4.6	13	2	302	2.09	23.5	LO	2.37	1.47	.4	.23	3.1	L3	L2	29	13	24	Sandy loam
Brycan loam	4-60	6.8	.3	3.0	8	1	198	.65	13.0	LO	2.15	1.35	.7	.24	3.3	L3	L2	28	14	28	Sandy loam
Ponil-rombo	0-10	6.0	.3	5.0	16	2	219	2.66	39.5	LO	3.55	1.21	.4	.25	3.6	L3	L2	26	12	21	Sandy loam
Ponil-rombo	10-40	7.6	.9	1.4	15	1	134	.15	13.1	HI	4.77	1.43	.8	.22	3.4	L3	L2	34	14	27	Sandy clay
Ponil-rombo	0-10	7.5	.6	2.0	10	1	142	.45	8.0	MED	1.54	1.95	.5	.24	3.2	L3	L2	36	16	33	Sandy clay
Ponil-rombo	10-40	7.5	.5	2.8	5	1	167	.36	10.9	HI	4.47	2.22	.3	.24	4.1	L3	L2	44	13	31	Clay loam
Brycan loam	0-4	7.1	.6	4.5	28	1	430	1.74	14.4	LO	3.98	1.87	.3	.26	3.9	L3	L2	39	15	31	Sandy clay
Brycan loam	4-60	7.4	.5	2.6	4	1	131	.37	9.7	LO	3.57	1.59	.3	.20	4.5	L3	L2	39	16	32	Clay loam
Stout-rock outcrop	0-4	7.3	.3	2.0	7	1	94	.41	23.9	LO	1.43	.66	.5	.24	3.6	L3	L2	24	17	32	Sandy loam
Manzano loam	0-18	7.0	.6	6.3	30	5	581	2.29	17.7	LO	3.39	2.41	.4	.22	3.4	L3	L2	30	15	34	Loam
Manzano loam	18-40	7.9	2.7	2.3	8	2	282	1.1	11.5	LO	3.06	2.83	.5	.24	3.4	L3	L2	30	12	27	Sandy loam
Rombo-rock outcrop	0-3	7.3	.4	3.0	7	1	188	1.4	14.9	LO	5.17	1.66	.3	.18	5.4	L3	L2	42	18	34	Sandy clay
Rombo-rock outcrop	3-23	7.5	.4	1.7	6	1	121	.26	14.8	LO	1.98	1.35	.4	.22	3.7	L3	L2	23	13	32	Sandy clay
Midnight-stout	0-4	6.8	.3	3.0	8	3	204	1.78	20.7	LO	7.34	1.14	.3	.23	4.0	L3	L2	23	13	23	Sandy loam
Stout-rock outcrop	0-4	6.2	.2	3.6	14	2	162	2.41	33	LO	5.92	2.19	.3	.23	3.6	L3	L2	27	13	23	Sandy loam
Stout-rock outcrop	0-3	6.7	.4	3.0	8	1	183	1.04	10	LO	4.19	2.49	.4	.21	3.6	L3	L2	37	12	26	Sandy clay
Rombo complex	0-3	6.5	.6	3.2	13	1	234	1.34	11.9	LO	1.43	1.72	.5	.30	4.3	L3	L2	32	16	30	Sandy clay
Rombo complex	3-23	7.5	.5	1.7	4	1	157	.77	12.9	LO	5.79	3.23	.6	.21	3.9	L3	L2	46	23	43	Sandy loam
Vamer-stout	0-3	7.4	.4	2.8	10	1	231	.93	11.0	LO	3.58	1.96	.3	.19	3.7	L3	L2	35	18	36	Sandy clay
Vamer-stout	3-14	7.1	.4	4.6	1	1	156	.94	8.1	LO	1.85	2.29	.4	1.5	3.3	L3	L2	33	18	44	Clay
Rombo-rock outcrop	0-3	6.5	.4	4.8	15	1	431	3.38	21.5	LO	9.99	1.58	.3	.15	3.7	L3	L2	33	16	29	Sandy loam
Rombo-rock outcrop	3-23	6.7	.4	2.8	4	1	152	.66	14	LO	3.21	2.19	.5	.18	3.4	L3	L2	36	21	40	Sandy clay
Manzano loam	0-18	6.8	.4	4.3	24	6	627	3.48	28.9	LO	4.01	1.6	.4	.18	3.4	L3	L2	24	17	28	Sandy loam
Manzano loam	18-40	7.7	.7	4.6	14	2	246	1.48	13.1	LO	4.21	2.19	1.2	.15	3.1	L3	L2	25	20	34	Loam
Manzano loam	0-18	6.8	.4	3.2	13	1	262	1.38	18	LO	2.97	1.63	.4	.13	3.3	L3	L2	32	16	30	Sandy clay loam
Manzano loam	18-40	7.6	.5	3.5	5	1	170	.72	10	LO	3.60	1.96	.3	.10	3.5	L3	L2	27	19	31	Sandy clay loam
Dargol-vamer	0-4	6.8	.3	4.5	10	1	179	1.31	19.3	LO	5.98	1.7	.3	.0	3.7	L3	L2	24	20	34	Sandy clay loam
Dargol-vamer	4-26	7.2	.5	2.5	6	1	178	.73	17.3	LO	7.38	2.31	.4	.10	3.8	L3	L2	32	22	44	Sandy clay loam
Ponil complex	0-10	6.3	.4	5.0	27	4	328	3.86	39.5	LO	3.03	1.92	.5	.14	3.9	L3	L2	26	17	29	Sandy loam
Ponil complex	10-40	6.7	.5	1.7	13	1	210	.69	17.8	LO	2.82	2.19	.9	.14	3.3	L3	L2	26	23	41	Sandy clay loam
Ponil complex	0-10	6.5	.3	4.1	13	1	275	2.35	18.5	LO	8.39	2.16	.4	.16	4.4	L3	L2	30	19	32	Sandy loam
Ponil complex	10-40	7.0	.4	5.8	12	1	185	1.67	12.8	LO	2.71	2.35	.4	.06	4.5	L3	L2	37	22	41	Sandy clay loam
Rombo-ponil complex	0-3	7.1	.4	4.6	13	2	370	1.98	13.5	LO	6.18	2.4	.3	.10	6.3	L3	L2	30	19	35	Sandy clay loam
Rombo-ponil complex	3-23	7.7	.5	2.2	5	1	153	1.5	14.3	LO	1.45	4.25	.3	.10	4.2	L3	L2	38	17	43	Sandy clay loam
Fuera complex	0-12	6.4	.5	5.9	19	1	225	2.8	39.9	LO	6.66	2.61	.4	.07	4.3	L3	L2	28	17	34	Sandy loam
Fuera complex	12-51	6.2	.3	3.1	7	1	165	1.15	34	LO	3.05	1.98	.4	.09	3.6	L3	L2	28	15	29	Sandy clay loam
Midnight ponil	0-4	7.4	.5	3.6	8	2	166	1.55	23.3	LO	7.22	1.44	.2	.09	3.0	L3	L2	26	19	40	Sandy loam

APPENDIX 2

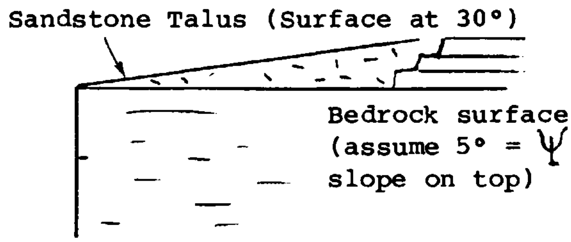
APPENDIX 2

DETERMINATION OF STABILITY OF TALUS ON THE HIGHWALL

Assume: W = 110 lb/ft^3, $\emptyset$ = 35° for sandstone talus.

Take the geometry as sketched below. Determine the factor of safety for the talus overlying the highwall top. The talus bed is approximately 800 ft. long x 50 ft. wide. It tapers from 15 ft. deep at the top of the talus to 0 ft. at the highwall crest.

W = 1/2 WHL = 1/2 (50'-15'-300')
W = 112 500 ft^3 at 110 lb/ft^3
W = 12 375,000 lbs.



The basal area of the talus pile is 50 x 300 = 15,000 ft^2. The normal stress on this base plane is:

δ = W cos Ψ /A = 12,375,000 lb. cos 5'/15,000 ft^2 = 821.86 lb/ft^2

The shear across this plane is:

τ = W sin Ψ /A = 12,375,000 lb. sin /15,000 ft^2 = 71.90 lb/ft^2

Limiting equilibrium is defined by:

W sin Ψ /A = W cos Ψ /A (tan $\emptyset$)

So that:

$$F \text{ (Factor of Safety)} = \frac{W \cos \Psi \tan \emptyset}{W \sin}$$

$$F = \frac{821.86 \text{ lb/ft}^2}{71.90 \text{ lb/ft}^2} (\tan 35")$$

F = 8.0 - reflecting the behaviour of the talus pile as a mass moving across the highwall top. That is, the talus pile is extremely stable.

As a check on the above, we know (Smith, Elements of Soil Mechanics for Civil and Mining Engineers, Gordon and Breach 1969) for Granular Material in the Geometry described that the Material (Talus) itself will behave according to:

$$F = \frac{\tan \phi}{\tan \theta}$$

Where θ is the angle at which the talus surface reposes.

Thus: $F = \tan 35°/\tan 30°$

$F = 1.21$

This reflects the behaviour of individual talus particles. That is, slope ravelling may occur but the talus pile is still shown to be stable.

With a less conservative friction angle (greater than 35°), the safety factor would increase accordingly.

APPENDIX 3

APPENDIX 3

KNOWN FORAGE VALUE OF MAJOR SPECIES USED FOR REVEGETATION

Plant Species	Animal Species	Value to Wildlife and Livestock
Trees		
Juniperus spp.	Elk	4% of summer diet, 4% of winter diet, 8% of spring diet
	Mule Deer	19% to 38% of summer diet
Pinus edulis	Mule Deer	Can be an important winter food source
	Birds	Important food and cover for pinyon jay. Also important for songbirds and turkey
	Deer and Elk	Browsed some; used for cover
Pinus ponderosa	Turkey	Preferred roosting cover. Also important for many songbirds and squirrels
	Elk	Cover
Pseudostuga menziesii	Elk	Up to 34% of winter diet and cover for deer and elk
Populus angustifolia	Mule Deer	Listed as a food item
Shrubs		
Atriplex canescens	Livestock	One of the most preferred shrubs
	Mule Deer	Browsed moderately during the summer
Cercocarpus montanus	Mule Deer	26% of the summer diet, 5% to 45% of fall diet, 6% to 16% of winter diet, 10% of spring diet
	Pinyon Mouse	Important food source
	Livestock	Good to very good browse; withstands grazing well

APPENDIX 3 (Continued)

Plant Species	Animal Species	Value to Wildlife and Livestock
Shrubs (Continued)		
Chrysothamnus nauseosus	Livestock	Flowers and new growth palatable
	White-Tailed Jackrabbit	Important food source
	Elk	A food source
	Mule Deer	An important food source
	Songbirds	Used some
Erotia lanata	Livestock	Valuable winter forage. Highly palatable and nutritious. High in crude protein
Quercus spp.	Turkey	Principal winter food source
	Mule Deer	12% to 27% summer diet, 24% of fall diet, 27% of spring diet
	Elk	4% of yearly diet
	Small Mammals	Acorns provide an important food source
	Cattle	Browse oak leaves to a limited extent
Rhus trilobata	Mule Deer	15% of summer diet. Browsed moderately throughout the year
	Small Mammals	Young shoots highly preferred
Yucca spp.	Mule Deer	20% of winter diet, 7% of spring diet
	Livestock	Succulent flowers highly palatable. Especially important during drought
Grasses		
Agropyron smithii	Elk	Up to 34% of summer diet, 1% to 67% of fall diet, 27% of winter diet
	Livestock	Palatable; produces moderately large amounts of forage and cures well

APPENDIX 3 (Continued)

Plant Species	Animal Species	Value to Wildlife and Livestock
Grasses (Continued)		
A. trachycaulum	Livestock	One of the most palatable wheatgrasses. Relished by all livestock
Andropogon gerardi	Livestock	Highly palatable during the spring and summer
	Turkey	Eat seeds
Bouteloua curtipendula	Livestock	Palatable and productive. High value year round
	Kangaroo Rat	Important food source
	Northern Grasshopper Mouse	Important food source
Bouteloua gracilis	Livestock, Mule Deer, Elk	Highly palatable. Cures well. May maintain 50% of nutritive value while dormant
	Northern Grasshopper Mouse, Plains Pocket Gopher, Ord's Kangaroo Rat	Important food source
Bromus marginatus	Livestock	Relished by all classes
Hilaria jamesii	Livestock	Moderately good food value for cattle
Festuca arizonica	Livestock and Wildlife	Palatable; important because of abundance
Muhlenbergia richardsonis	Livestock	Palatable
Panicum obtusum	Livestock	Fair to good forage for all livestock
	Turkey	Important food source
	Songbirds	Seeds important for many species
	Muskrat	Important food source
Poa pratensis	Livestock and Wildlife	Extremely palatable for all livestock. Especially important to seed eating birds
	Chipmunk, Pocket Gopher and Mule Deer	Important food source

APPENDIX 3 (Continued)

Plant Species	Animal Species	Value to Wildlife and Livestock
Grasses (Continued)		
Sitanion hystrix	Livestock	Moderate palatability for cattle
Sporobolus cryptandrus	Livestock and Wildlife	Palatable to cattle, cures well
	Turkey	A food source
	Junco	Important food source
Stipa comata	Livestock	Highly palatable before seed production
Forbs		
Achillea lanulosa	Livestock	Grazed moderately
Artemisia frigida	Livestock	Fair to good forage, especially fall through spring
	Mule Deer	18% of winter diet, 9% of spring diet
Penstemon strictus	Mule Deer	26% to 38% of winter diet
	Pinyon Mouse	Important food source
	Northern Pocket Gopher	Important food source

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ENVIRONMENTAL REGULATION - HOW EFFECTIVE?

by

D.M. Galbraith
Ministry of Energy, Mines and Petroleum Resources

ENVIRONMENTAL REGULATION - HOW EFFECTIVE?

This paper presents one view of the world of environmental regulation. It is a world made up of the elements of Legislation, Administration, Industrial and Environmentally related Economies, the Media and the Public. How these elements tend to relate bears considerable influence on the effectiveness of environmental regulation; and much land reclamation is done in conformity with regulations.

Regulations bring different associations to different people. To the free-enterpriser they weave a rope by which he is strangled; to the bureaucrat they weave a fabric which often fails to cover the critical parts. Both would agree they absorb a great deal of energy. Because regulations are becoming more and more a fact of life in land reclamation it is useful to speculate on their impact, their effectiveness and on the environment within which they are written. We can start with an historical look at mine regulation in British Columbia.

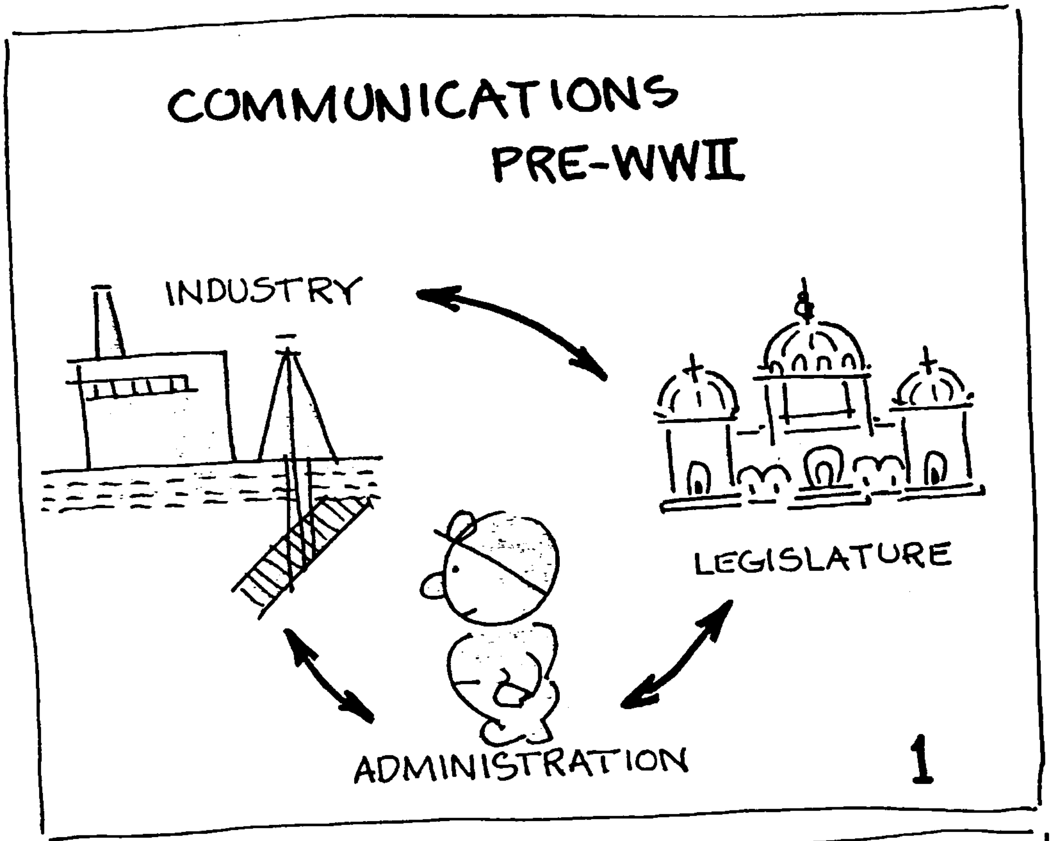
In the past the exercise of regulations involved an inspector, the industry, and the authorizing legislation (Figure 1). The effort required to be invested in communications was minimal.

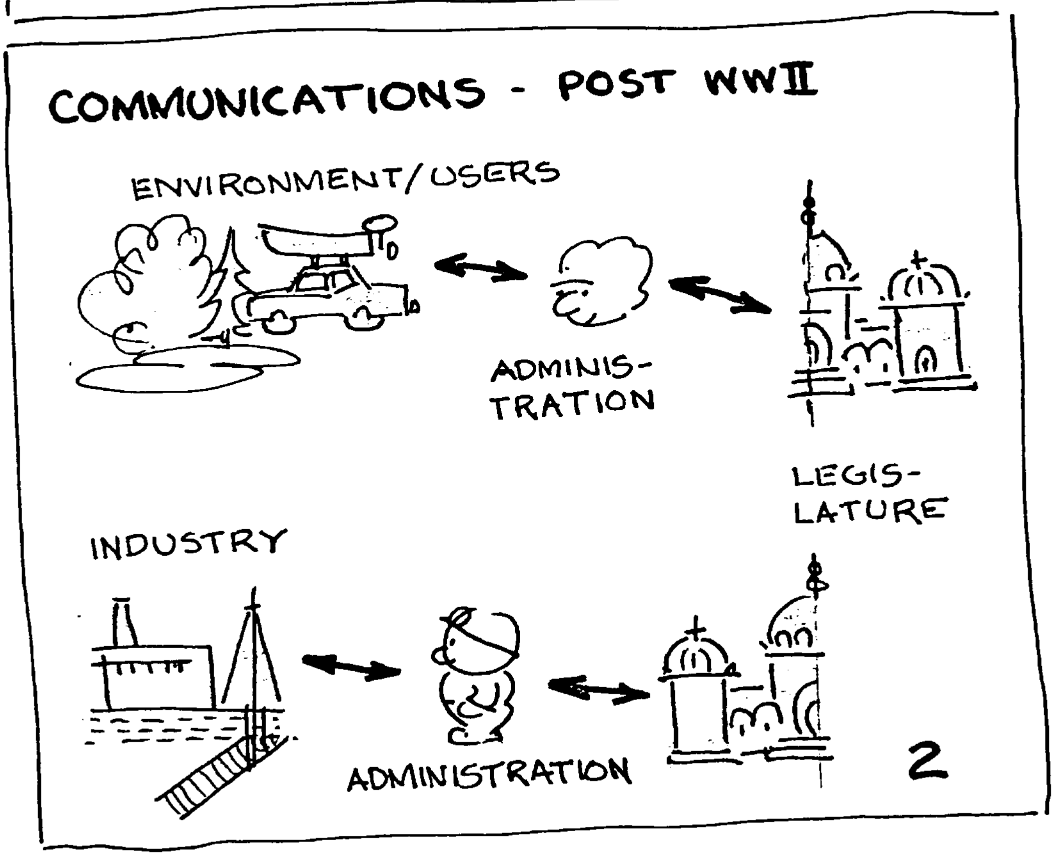
This picture changed, however, after the Second World War. The Government was reminded at this time by the new generation that past activity had left obvious gaps in the landscape and a renewal was due. The response was the creation of new legislation and administrative machinery. The situation started to become complicated (Figure 2).

On the minesite the new standards increased both the cost of work undertaken and the cost of management. By trial and error mine managers discovered that internal environmentally influenced decisions could be made as indicated in Figure 3. Certain functions were assigned to given sections, while some decision making was shared. It was determined that in balancing environmental risk against cost, decision making was most effective if advice came directly from the environmental authors rather than through engineering (Figure 4). Decision making took more energy than it used to, but it was still possible.

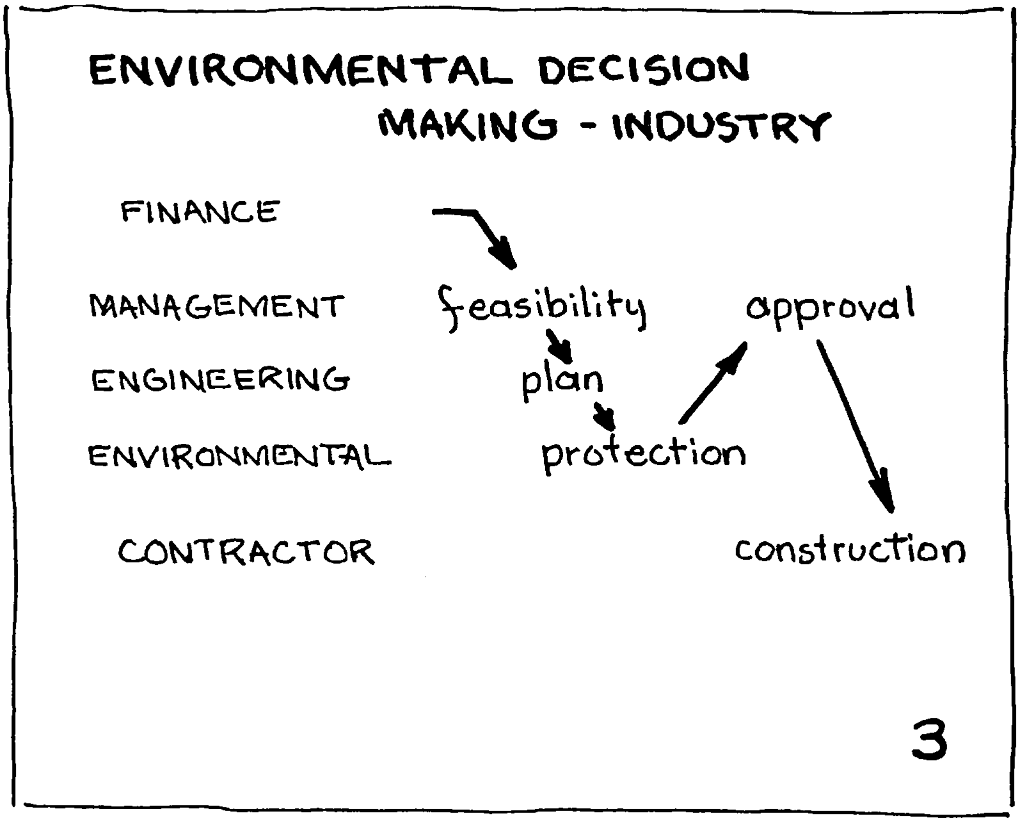
Within government, however, two systems of communication developed. They could be called the Mine Development System, and the Environmental System. System in this context does not infer an organized hierarchy

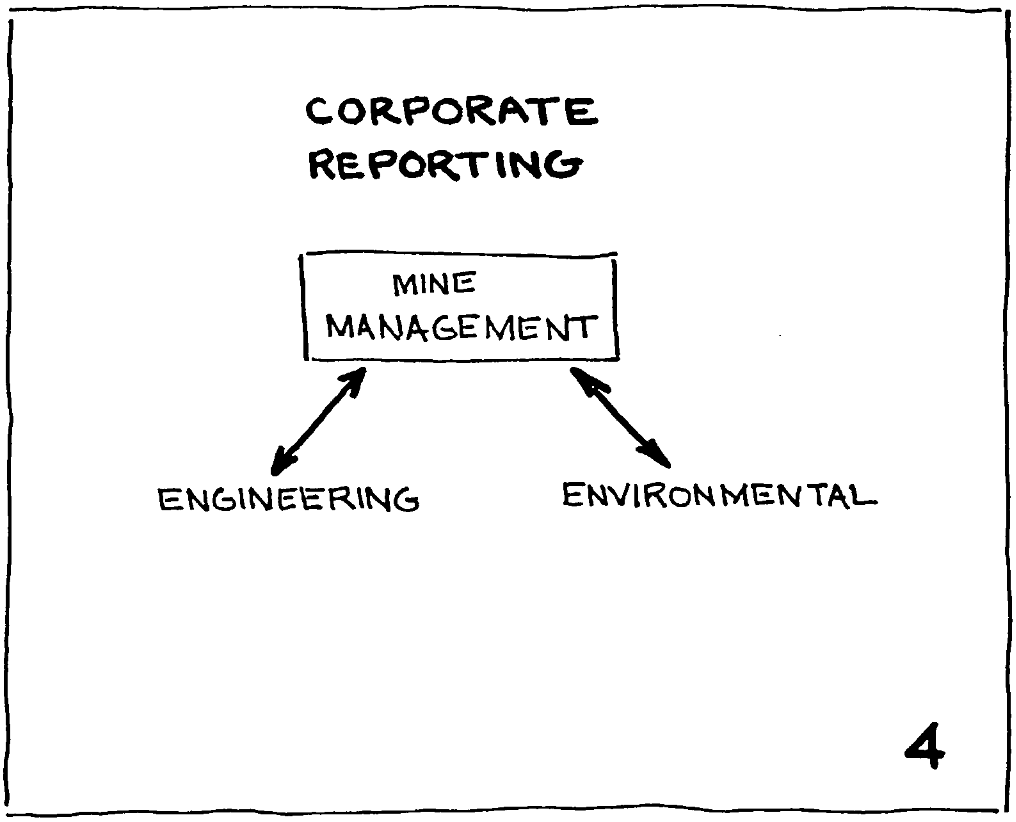
FIGURES 1 AND 2





FIGURES 3 AND 4





structured to deal systematically with issues. It is the one suggested by the social scientist, and is based on a tendency to communicate in a given pattern (Figure 5). Communication along the lines shown must be conceded to be much greater than that which exists between the systems shown, not that that makes for better decisions, but that more clearly reflects how bureaucracies tend to interface.

Each of the systems noted has a particular philosophy. Mine development is coal-oriented in keeping with industries' requirements, and regulation is achieved through approval of work method. The philosophy of the environmental system on the other hand is protective. It responds, or reacts, in part to the first system, and regulation is oriented to definition of pollution limits and enactment cf reserve areae.

These two systems consume a great deal of each other's energy. They do however, avoid much confrontation because the application of their efforts and respective legislations is to two different aspects, as noted. In considering effectiveness then it should be remembered that there are these two viewpoints from which to judge.

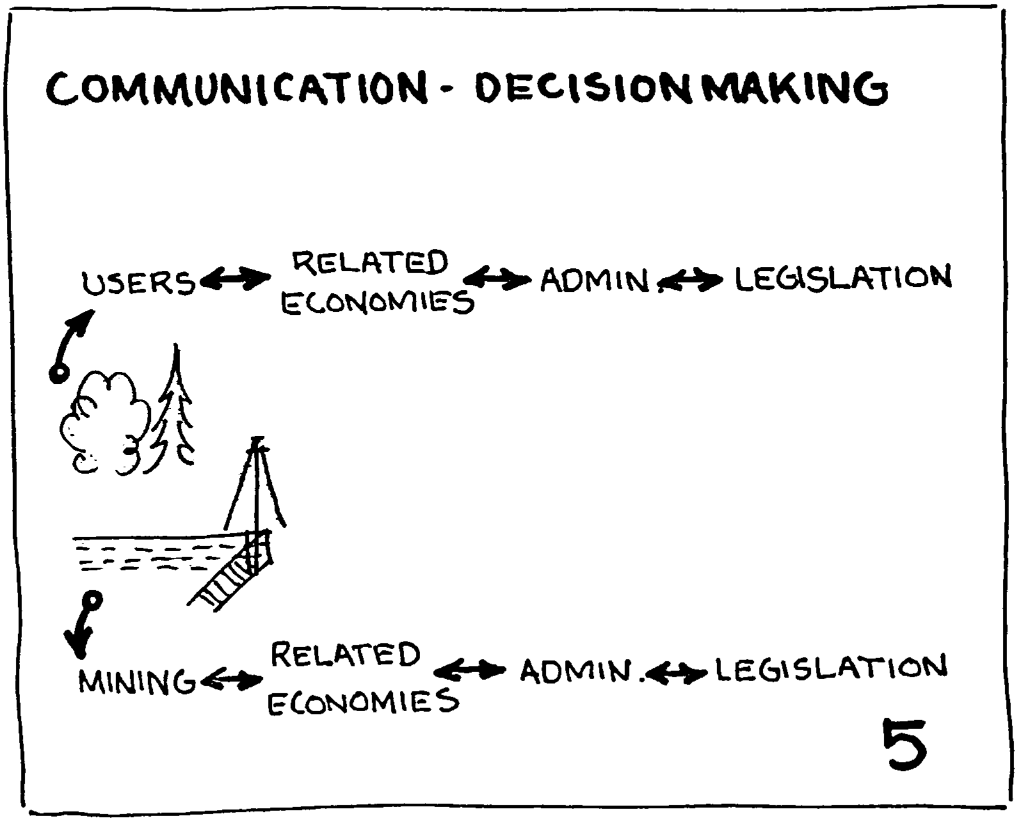
There is also a third, that of the industries. Their concern is for cost and schedule, most critically during the pre-construction phase of a new development proposal.

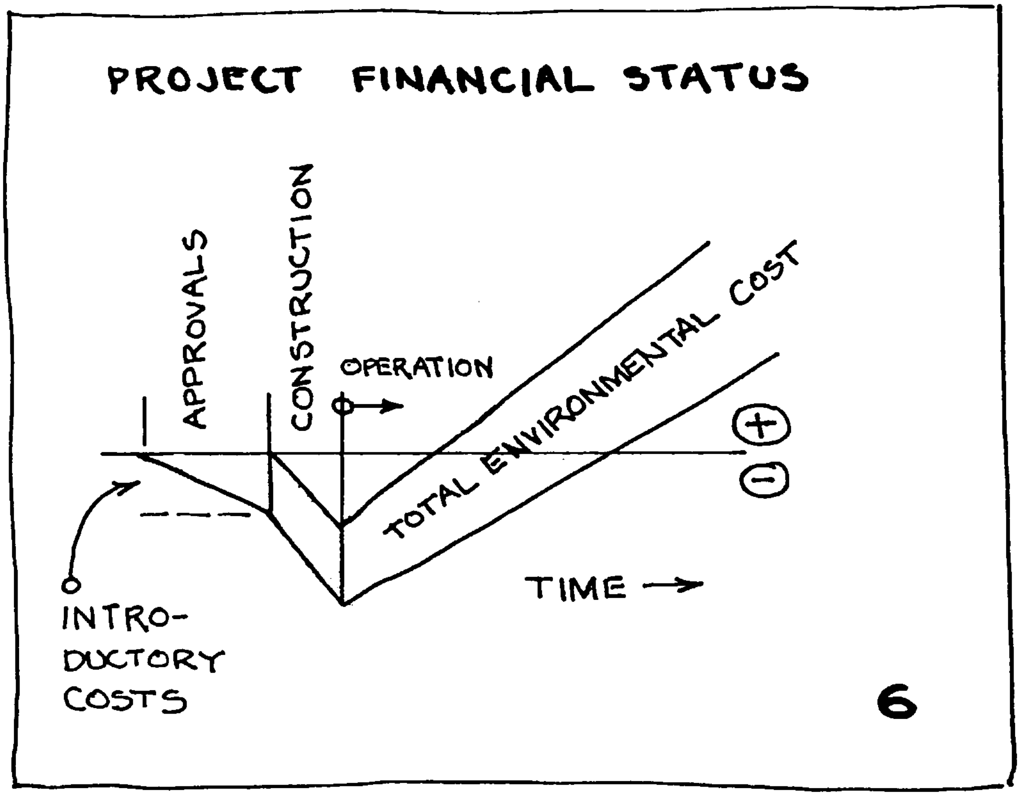
When such a proposal is made which will increase mining activity, and therefore also that of the affected environment, both systems previously suggested place a manpower demand on not only the project, but on each other.

On a time scale, this occurs at the project's period of maximum deficit (Figure 6). The environmental scale has been magnified in the illustration, as in actuality environmental costs may only be in the order of 5% of operating cost. This cost is bearable during operation, but it is critical when front-end money, and the possibility of a "No", and time delay is also faced. Several factors will influence just how large the introductory deficit will be:

A the extent of environmental resources affected.

B the effectiveness of the environmental planning done by the company.


COMMUNICATION - DECISIONMAKING
USERS
RELATED ECONOMIES
ADMIN.
LEGISLATION
MINING
RELATED ECONOMIES
ADMIN.
LEGISLATION
5


PROJECT FINANCIAL STATUS
APPROVALS
CONSTRUCTION
OPERATION
TOTAL ENVIRONMENTAL COST
+
−
TIME →
INTRO-DUCTORY COSTS
6

C the effectiveness with which the two systems previously described can work together.

D the attention focussed by the media.

An engineer would be inclined to write an energy conservation equation to describe the work required of the company to satisfy the demands of the regulatory machinery:

$$E = \text{EFFORT} = \frac{A \times D}{B \times C}$$

He might have trouble with the units, however.

To justify inclusion of the role of the media in the above equation, we have to go back to the two-system diagram and add to it, not only the media element but that also of the public (Figure 7).

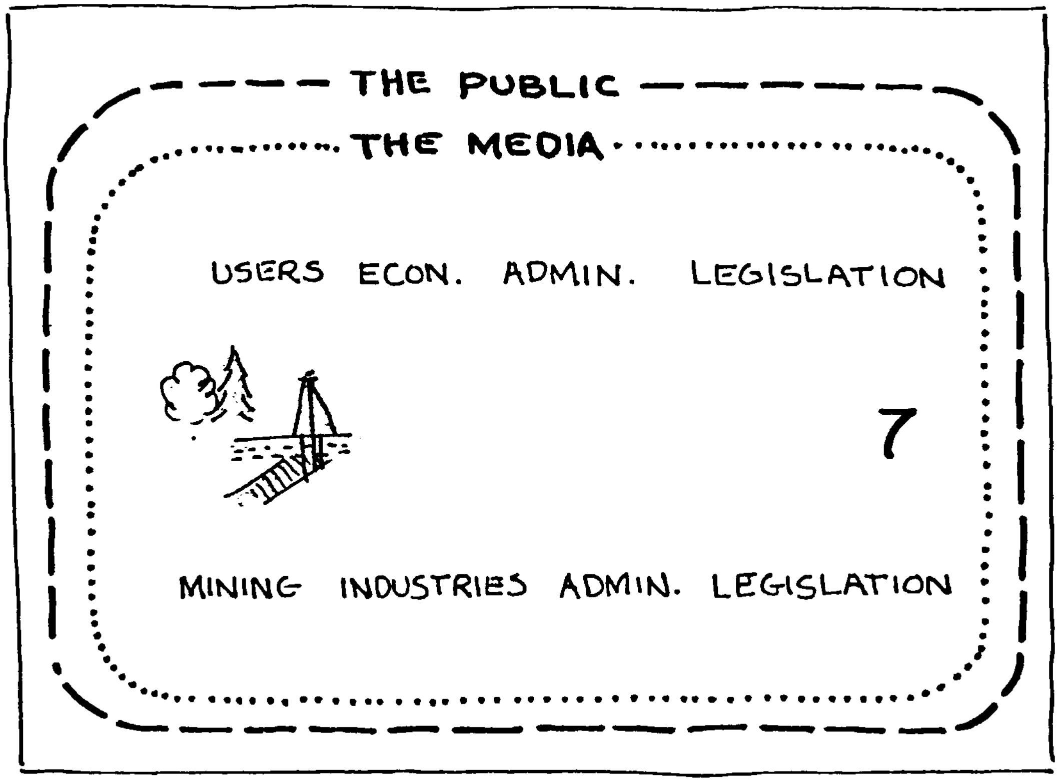
The media survives by merchandising the news to the public. The public's desire (and that includes you and me) is to be sensationalized. The inclusion of a heavy interpretation toward disaster serves both groups.

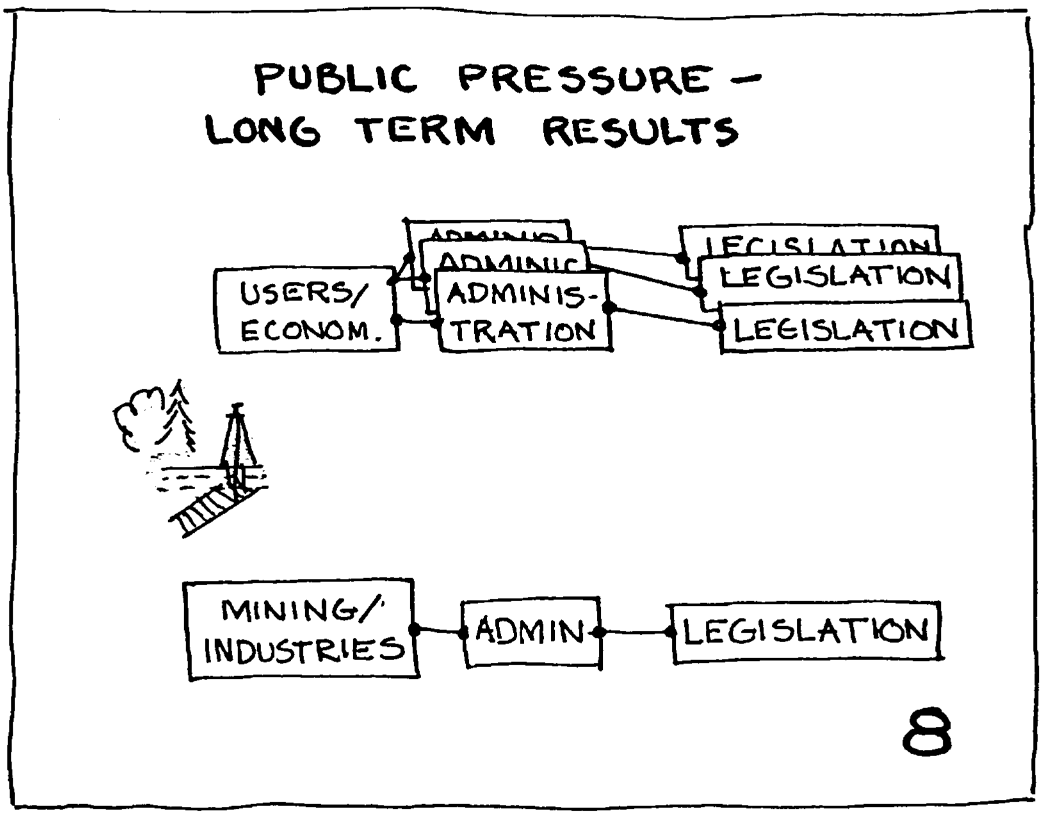
By focussing generally on the environmental side and more particularly on the project proposal phase, the media, as a system, survives. In the process, however, much public energy is directed not only toward the project but toward the administrations and legislation.

The result of this concentration is felt in two ways: in the short run by the particular project, in the form of an increased requirement for environmental design; and in the long run by an increase in the amount of regulation required, and in the number of regulatory bodies created. Although the media's attention is fickle, and our current favour may simply be a fill-in between World War II and the energy crisis of the next millenium, it is still critical.

The more far-reaching of the two results is the long-run one. This is depicted in Figure 8 by an addition in the number of regulatory loops created in the environmental circuit. This changes the equation which was proposed to describe the work requirement exacted from industry. There are now more people to "get around to". If we assume that there

FIGURES 7 AND 8





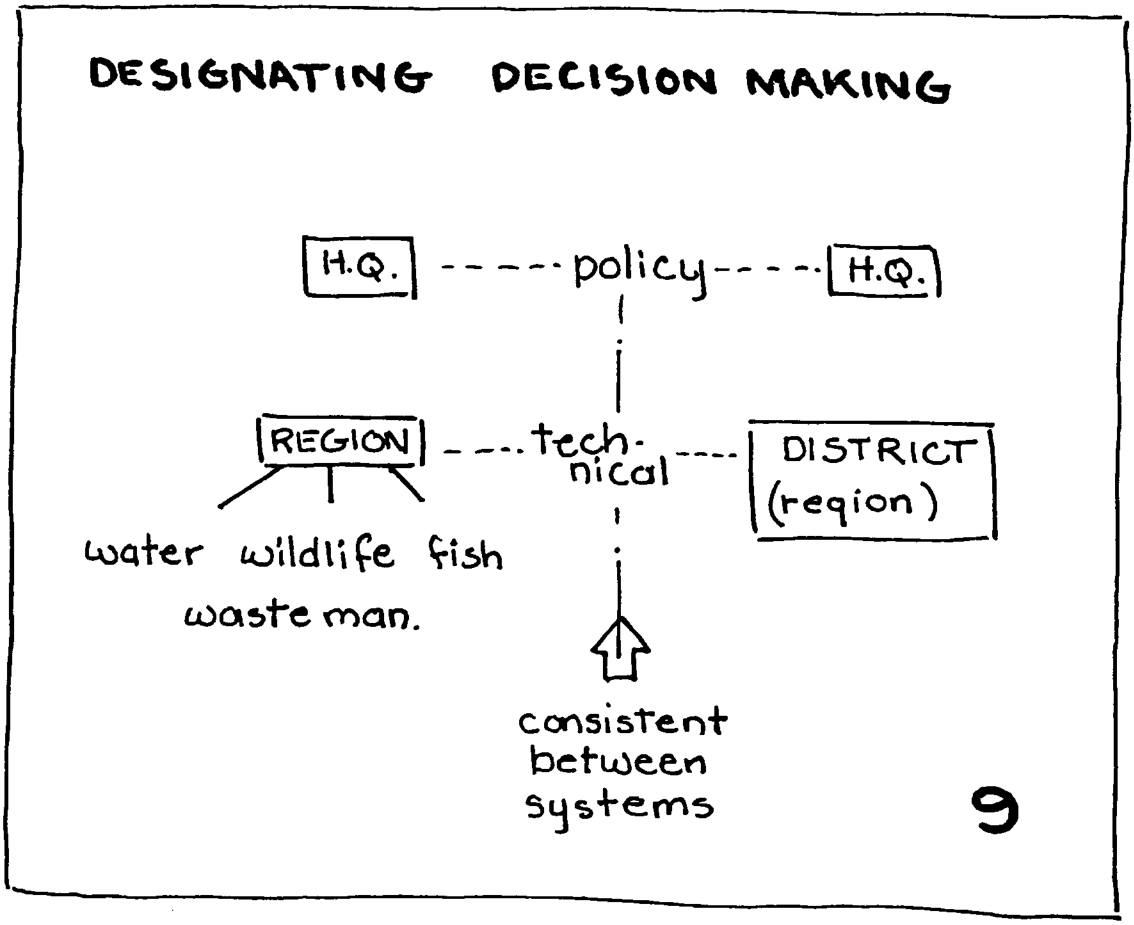
is no overlap in jurisdiction there may be no problem. But unfortunately many of the environmental sections of various acts do overlap, and factor "B" - the effectiveness of environmental planning done by industry - can be reduced. Further with respect to factor "C" - the ability of the two basic systems to work together - it was suggested that effort undertaken by one system induces an energy requirement from the other. More regulatory loops mean a greater work commitment, but unless considerable care is taken, no greater efficiency will result. I would like to argue, for reasons that are as old as the first bureaucracy, that growth is more predictable than efficiency, and future projects will tend to be forced deeper into a preliminary deficit.

The multiplication in loops includes not only the Provincial but the three other levels of Government. Being somewhat insulated from each other the jurisdictional overlap expands without too much mutual confrontation, but with progressively higher demand on the project. One result of this is that over a period of time the development dice become loaded in favour of larger companies, as they are the ones that can better afford the introductory costs. They may feel that they are being penalized the heaviest, but there is an argument that in comparison it is the smaller companies who are faring worse. The status of the sand and gravel industry provides evidence to support this.

In summary of the above, there are three viewpoints from which the effectiveness of environmental regulations can be judged: the mine agencies'; the environmental agencies'; and the industries'. It may be unrealistic to speculate on absolute numbers in this regard, however, it can be productive to consider ways and means of improvement.

We can start by searching our experience for examples of procedures that work (better) - and then speculate on the reasons "Why". Some do come to mind, for instance, the Regional Advisory Committee on Reclamation, which recommends preliminary approval to coal exploration proposals. This Committee resolves technical questions and problems in the region, and refers the ones that cannot be agreed upon, and policy conflicts, to Victoria (Figure 9). In 1980 in total 81 projects were reviewed without a single need for referral. This exercise has effectively brought the application of each Provincial Ministry's Regulations into alignment in technical terms, on the site, where they can be discussed with the companies.

FIGURE 9


DESIGNATING DECISION MAKING
H.Q.
policy
H.Q.
REGION
technical
DISTRICT (region)
water
wildlife
fish
waste man.
consistent between systems
9

The Regional Resource Management Committee is another example of the attempt to bring regulations into agreement. Two other examples of experimentation could be noted the ELUC Secretariat; and the Ministry of Deregulation.

Two things might be said of all of the above noted experience. Firstly, it would be surprising if the objective of more effective regulation could be reached through unilateral effort by one level of Government, when all four are involved, plus industry. It is a start but we are looking at only one of the dimensions of the problem.

Secondly, we may be ignoring sources of assistance which could be utilized in the development of more workable systems. That of the universities is suggested. Not particularly in the environmental field, but more generally in the administrative and social sciences areas, for it should not be forgotten that we are as much trying to make the machinery of Government function as to improve environmental practice. If I read my mail correctly the Banff School of Environment is working toward this view.

Research will play a key role in any attempt to improve administrative/ environmental practice. For example, it benefits the Mineral Resources Branch, the environmental agencies and the industry to have functioning such a workable arrangement as the Regional Advisory Committee on Reclamation, but it would be even more beneficial to have an analysis undertaken to document why such arrangements work and the nature of their limitations.

Questions for research might be considered in four areas:

1. The costs of environmental regulation:

   - to the environmental agencies.
   - to the mines regulation agency.
   - to the industry, both direct and indirect.

2. The benefits of environmental regulation:

   - in economic terms (if this is possible - which I doubt - with apologies to the economists).

- in comparative terms, i.e. on specifically determined sites, what is the significance of the resources that have been salvaged?

3. The effect on cost and benefit of making given changes in the systems described.

4. The resources that Government, industry and higher education can contribute to experimentation with change.

The above are types of questions which have been posed predominantly by engineers and biologists for decades. The answers which have been supplied have not been entirely satisfactory, and part of the reason for this is that they are usually provided by other engineers and biologists. The missing response has been that of the organizational analyst. He is usually found on campus attracted by the academic climate. Although rarely seen, this specialist in the social sciences has a contribution to make, additional to those of the physical and natural. His toys are not the trucks of the engineer or the species of the biologist; they include such things as organizations, goals, communication, decision making and change.

Before the field of environmental regulation develops further either through design, or by lack of design, this view could profitably be consulted, and the research previously referred to undertaken.

A further question is prompted then: Who would consult this view, and who would oversee the research?

The success of the Technical and Research Committee on Reclamation suggests that a panel or representative group from Government, industry and university might provide the balance necessary to support objective work. Considerable thought would be required to determine its feasibility, but it would seem to be worth the effort of trying.

This suggestion may appear to you to be wandering too far from the pragmatics of regulation. The alternative to doing things in a planned way, however, is to have events thrust upon you. B.C. has had its uranium inquiry and Ontario its sand and gravel review, to give only two recent examples of this. If a portion of the cost of inquiries such as these were invested in ongoing administrative research, I feel their cost would go down, their benefit would go up, and their frequency would reduce.

In conclusion it is argued that:

- There is a tendency for environmental regulation to become less rather than more effective.

- The workings and problems of the regulatory systems which are involved are more complex than we are usually prepared to give credit.

- The best bet for improvement in effectiveness lies in the application of social and more particularly organizational science to understandings developed to date by the physical and biological sciences.

- This exercise should be conducted within a forum which includes the viewpoints of Government, industry and university.

Further speculation should await criticism. Yours would be appreciated.

THE AFFORESTATION OF OPEN-CAST MINING SPOILS IN THE UNITED KINGDOM - SOME TECHNIQUES AND OBSERVATIONS

by

D.F. Fourt
Forestry Commission
Farnham, Surrey, U.K.

THE AFFORESTATION OF OPEN-CAST MINING SPOILS IN THE UNITED KINGDOM - SOME TECHNIQUES AND OBSERVATIONS

The decision as to whether to afforest former open-cast mineral workings is mainly determined by economic considerations. On the better soils, and where the topsoil has been conserved, a return to agriculture is to be expected. Where there is a high water table, on river floodplains, lakes and ponds are the result, valuable for recreation and amenity. On poor soils, under heath or moorland vegetation, and on former woodlands, the sites are usually afforested.

When carrying out reclamation we usually have the benefit of a survey, where slopes and other features can be considered. Our studies have emphasized the need for land-forming to provide gradients of around 4° to 5°. Where the area concerned is level, or less than this, we specify ridging, 30 m x 1.5 m (Figures 1 and 2). The site is then deep-ripped to 75 cm, with a Caterpillar D8, with 3 winged tines in a multi-shank ripper parallelogram frame (Figure 3). The 75 cm of rooting depth (Figure 4) provides around 15 cm of rainfall equivalent, essential for trees, but not always for grass or herb cover.

Where the surface has been ridged, the land is cross-ripped to lead excess rainfall to the gullies and on to a permanent watercourse. On heavy-textured spoils, a set of heavy discs is used to raise the planting position.

Many of the sites returning to forestry have no topsoil, or else it has been lost during mining, particularly in the uplands of South Wales. On such sites, and also on some topsoiled areas, deficiencies in the plant nutrients, nitrogen, and occasionally phosphorus, can be identified by foliage analysis of the young tree. We have found that in several geological strata - coal measure shales, brick clays, and sometimes in overburden materials - that there is some fossil nitrogen, which is released during the first 5 to 6 years after mining, after which the trees become severely deficient.

Our recent practice, when planting trees on shale spoils, has been to sow seeds of the unpalatable *Lupinus* and *Lathyrus* species between the rows to build up nitrogen capital to the 700 kg/ha needed to achieve canopy closure.

FIGURE 1

LAND FORM FOR RESTORATION OVER POROUS SANDS. RIDGES RIPPED ACROSS BY D8 WITH MULTI-SHANK RIPPER, TOOL POINTS AT 75 cm. VERTICAL SCALE 2 TIMES HORIZONTAL.

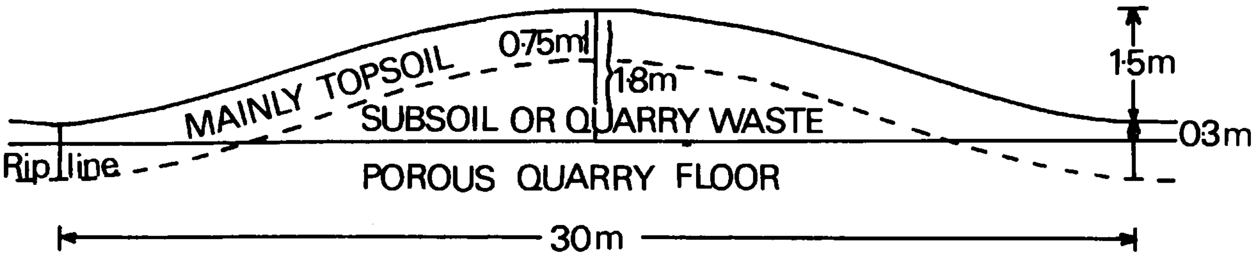


FIGURE 2

LAND FORM FOR RESTORATION OVER IMPERVIOUS MATERIALS. RIDGES RIPPED ACROSS BY D8 WITH MULTI-SHANK RIPPER, TOOL POINTS AT 50 cm. DRAIN PUT IN BY SIDE-ACTING DIGGER. VERTICAL SCALE 2 TIMES HORIZONTAL.

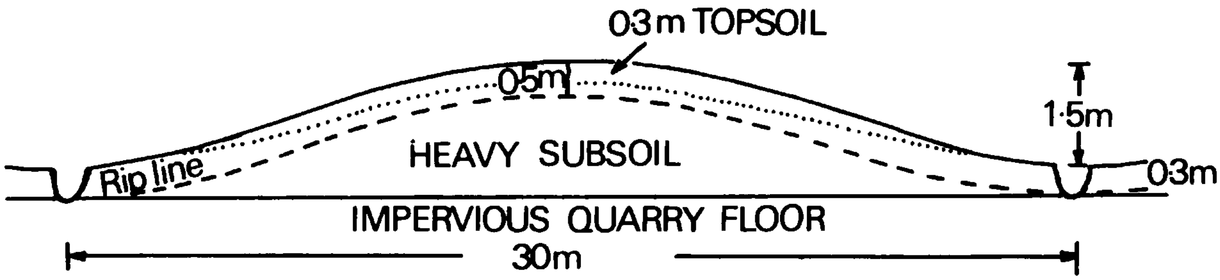


FIGURE 3

DIAGRAM OF WINGED TINE SET AT 30°,
PATTERN OF SOIL DISTURBANCE IS SHOWN IN FIGURE 4

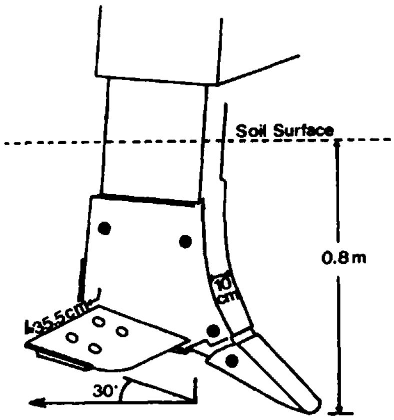
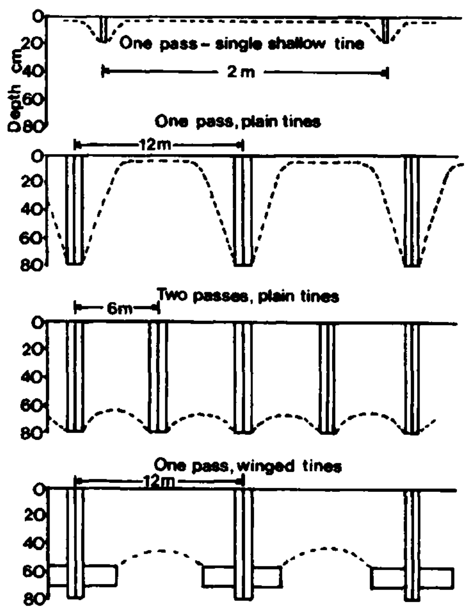


FIGURE 4

DEGREE OF SOIL DISTURBANCE RESULTING FROM PLAIN AND WINGED TINES



Older, slow-growing tree stands, on mining spoils are much more difficult to treat. Foliage analysis - a standard system among foresters in most countries - has shown that nitrogen is usually the limiting nutrient element. We have to either spray sewage liquids or other cheap organic wastes, or try to introduce nitrogen-fixers such as alders. The wildlife, mainly deer, hares and rabbits, plus free-ranging sheep trespassing on the sites, rapidly remove all seedlings of nitrogen-fixing species which seed in naturally, or the palatable species, where sown, and prevent the natural build-up. In consequence, fencing as well as a choice of unpalatable or even toxic legumes are essential.

Among the commercial tree species being planted, we find the larches particularly successful at obtaining mineral nutrients from spoils, and are tolerant of low nitrogen supply. Corsican and *Muricata* pines are also very suitable, particularly in the lowlands. Lodgepole pine has been found to be surprisingly inefficient at taking up phosphorus from the high pH coal spoils, and also suffers severe bud damage from the moth *Rhyacionia buoliana*. Among the broadleaves, the maples and birches are valuable, especially in mixture with one of the alder species, to fix nitrogen. Alnus litter seems particularly palatable to worms, on base-rich spoils.

Regarding mycorrhiza, we have found that nursery stock is usually well furnished and there is little indication that the trees lack suitable organisms. With nitrogen as the main limiting factor, the ability to fix atmospheric supplies is the most useful attribute.

We consider that foliage analysis and replicated trials offer the best system to enable the experimenter to concentrate on those nutritional factors limiting tree-growth, especially at a time when economic pressures are pressing.

NATURAL REVEGETATION OF EXPLORATION TRENCHES IN THE STILLWATER COMPLEX OF THE BEARTOOTH MOUNTAINS, MONTANA

by

David W. Wheeler
and
John O. Sawyer
Humboldt State University
Arcata, California

NATURAL REVEGETATION OF EXPLORATION TRENCHES IN THE STILLWATER COMPLEX OF THE BEARTOOTH MOUNTAINS, MONTANA

ABSTRACT

In 1971 and 1972 Anaconda Copper Company reclaimed a series of mineral exploration trenches located in the Beartooth Mountains of Montana, Custer National Forest. The work was done following U.S. Forest Service prescriptions and resulted in backfilling the trenches and extensive seeding of exotic species of three grasses and one clover. From an examination of photographs taken 1971 to 1975 and subsequent site inspections, it is apparent that the initially high cover of exotic species has declined, and native plants from surrounding areas have begun to colonzie the reclaimed trenches. A study was conducted during 1979 to 1980 to identify those native species.

The trenches are located in the basal zones of the Stillwater Mineralized Complex at elevations ranging from 2,500 meters to 2,835 meters. Surrounding vegetation types include *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium, Pinus albicaulis-Abies lasiocarpa, Pinus albicaulis,* and dry alpine.

Colonization on the trenches was found to be positively correlated with the surrounding undisturbed vegetation types. There was an assemblage of native species that were mainly restricted to colonizing trenches that extend into or through the dry alpine and timberline habitat types. There was another aggregate of species that were associated with the *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* habitat type. Successful colonizers which are locally abundant should be used as seed sources for subsequent reclamation of disturbances in the Complex and in other areas of similar habitat type. Further studies should be conducted to develop seeding recommendations for other habitat types throughout Montana.

INTRODUCTION

Disturbances due to mining can be environmentally damaging in any area, but in mountains the disruption is greatly increased. Mountainous areas with steep, unstable slopes, shallow soils, and high winds and precipitation are not only very susceptible to erosion, but the erosion rates after comparable disturbance are greater than in lowlands (Ives 1979).

Not just the aesthetic, recreational, wildlife habitat, grazing, and watershed values of the mountains suffer, but also areas of erosional deposition, far from the original disturbance, are affected (Brown et al 1976, Ives 1979). Some means of reclaiming these mining disturbances should be found to mitigate the loss of the inherent values of mountainous areas. In most cases, the establishment of plant cover is the primary means of reclaiming these disturbed areas (Brown and Johnston 1978).

When revegetating mining disturbances, the primary concern is plant establishment and survival with minimal maintenance (Kenny and Cuany 1978). This goal is already difficult to attain in the harsh environment of mining spoils, but the problem is compounded at high elevations where most of the commonly used, commercially available, non-native plants are close to, or beyond, the limits of their environmental tolerance. It has been shown that using adapted, native plants is the most effective way to meet this challenge (Monsen 1975, Brown et al 1976, Billings 1978, Brown and Johnston 1978, Wagner et al 1978). Native plants that are best adapted for revegetation, are those pioneer species that are most active in colonizing the disturbed areas (Brown et al 1976, Billings 1978, Brown and Johnston 1978). Planting these pioneer species should then increase the rate of subsequent natural succession by a process referred to as "nucleation" (Yarranton and Morrison 1974). These pioneer, or "nuclei", species act as centres of propagule dispersion, and succession proceeds as an increase in size of these patches of persistent species until they coalesce to form a more continuous vegetative cover. Environmental modification resulting from this cover then promotes further succession toward a climax vegetation. This is essentially what is meant by the term "natural revegetation". Revegetating an area consistent with, and thereby speeding up, natural succession.

Gates (1962) conducted one of the early studies on high altitude revegetation in Idaho. His first seeding attempts were made using commercially available, non-native grasses, and mulches of sawdust and conifer boughs. Despite an excellent initial establishment, nearly all seedlings had succumbed to the rigorous environment by the middle of the second growing season. Further seeding attempts were made using a mulch made from native hay, containing viable seed, that was cut from surrounding areas. Again, initial establishment of grasses was good, but by the end of the growing season, nearly all introduced grasses were dead and only native grasses from the seed in the mulch had survived. These native grasses not only survived, but "...appeared to be well established and thriving." In addition, other native plants from the surrounding vicinity had begun to colonize the mulched plots. Gates concluded that "...the native species appear to be much better adapted to the environmental extremes of the site and become established where exotic species fail."

Brown et al (1976) conducted revegetation studies at the McClaren mine on the Beartooth Plateau, using both native colonizers and commercial seed mixtures. At the end of the first growing season introduced grasses were taller, had higher production levels, and generally were more vigorous than native grasses. However, by the end of the third growing season the productivity and vigor of the introduced grasses had declined. The native grasses were much more vigorous, had greater productivity, and had even begun to invade plantings of introduced grasses. When transplanting native and introduced grasses in the same area, Brown and Johnston (1978) found that the native plants had an average first year survival rate of 75%, whereas the introduced species had only 39%. Also the native species had a higher level of productivity.

In February of 1971, representatives of the Custer and Gallatin National Forests met with officials of the Anaconda Copper Company to discuss ways to minimize environmental impacts due to mineral exploration. A direct result of this meeting was that Anaconda voluntarily agreed to reclaim disturbances in the Beartooth Mountains (Anaconda Copper Company 1975). The disturbed sites were surveyed and mapped in the summer of 1971. The following summer, the sites were graded to approximate original contour, and subsequently seeded using U.S. Forest Service technical assistance and advice. The seeding recommendation used consisted of commercially available, non-native grasses and a clover.

As a part of their reclamation procedures, Anaconda produced a pictorial review of the revegetation work starting in the summer of 1971 and continuing through September of 1975 (Anaconda Copper Company 1975). From these pictures and a current inspection of the trenches, it is readily apparent that the results are similar to the findings of Brown et al (1976) when using seed mixtures of introduced grasses. At the end of the first growing season, most of the trenches supported a lush growth of grasses. Since then, the vigor and productivity of the seeded vegetation has declined. Native grasses, herbs, and trees are now colonizing the trenches from the surrounding undisturbed areas.

The purpose of this study was to identify those native plants that are best adapted for revegetating high elevation exploration trenches in the Stillwater Complex of the Beartooth Mountains, Montana. Successful adaptation of a species to the disturbed environment of the trenches would be indicated by that species having high colonizing frequency. Identification of colonizers that are locally abundant could then be used as the basis for recommending seed sources to be used in subsequent reclamation, thereby improving the chances of effective revegetation of these and other mining related disturbances (Bell and Bliss 1973, Greller 1974, Brown et al 1976, Wali and Kollman 1977, Billings 1978, Brown and Johnston 1978).

STUDY SITE

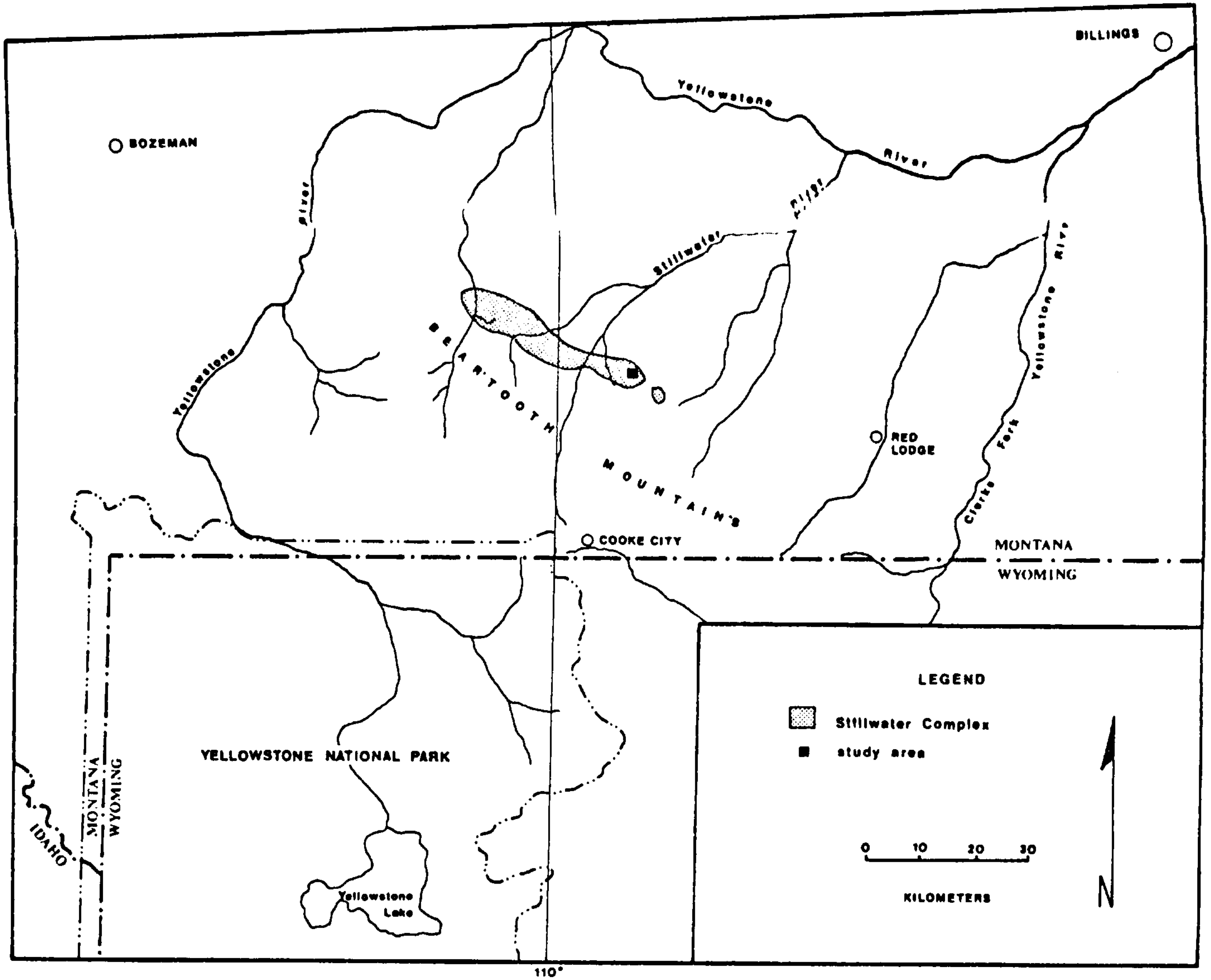
The Beartooth Mountains, a front range of the Rocky Mountains, are located in southern Montana and northwest Wyoming. The range is about 130 km long and 50 km wide. The mountains extend southeasterly from the Yellowstone Valley near Livingston, Montana to the canyon of the Clark Fork of the Yellowstone River, 50 km northeast of Cody, Wyoming. They rise from the Great Plains at 1550 m to almost 3960 m, with a major plateau about 3050 m. The range consists primarily of an uplifted pre-Cambrian granitic block, with numerous basic intrusions and diabase and pegmatitic dykes (Bevan 1923, Loverling 1929).

Climatically, the Beartooth Mountains are similar to other high altitude regions in the Rocky Mountains (Baker 1944, Johnson and Billings 1962, Thilenius 1975, Brown et al 1976). There is a short growing season of 60 to 70 days with high solar radiation loads and cool summer temperatures, with the possibility of frost at any time during the year (U.S. Forest Service 1978). Average maximum and minimum temperatures range from 0°C to -13°C in January, and from 24°C to 9°C in July (National Oceanic and Atmospheric Administration 1971). Annual precipitation is estimated between 115 cm and 152 cm, with most falling as snow in the winter months, September through June (Brown et al 1976, NOAA 1971).

The Stillwater Complex is a highly mineralized zone about 50 km long that lies in a band along the northeast face of the Beartooth Mountains (Figure 1). The Complex is of igneous origin and is separated into a

FIGURE 1

REGIONAL SETTING OF THE STILLWATER COMPLEX, INCLUDING THE STUDY SITE



succession of extensive sheets lying one on top of the other. This layering can be divided into four basic zones: a) the Basal Zone (approximately 70 m thick) of medium grained noritic rocks; b) the Ultramafio Zone (1200 m to 1800 m thick) repeating layers of bronzitite, granular harzburgite, poikilitic harzburgite, and chromitite; c) and d) the Banded and Upper Zones (in aggregate approximately 4200 m thick) layers of norite, anorthosite, troctolite, and gabbro (Jones et al 1960, Sullivan and Workentine 1964).

The exploration trenches in this study were dug in the basal zone of the Stillwater Complex by U.S. Steel in the late 1950's and early 1960's. The claims containing these trenches were later transferred to Anaconda Copper Company. The trenches are located just to the south of the Benbow chromite mine in Custer National Forest. There is a total of 20 reclaimed trenches following, and usually dug perpendicular to, the basal zone. The trenches are between 6 m and 12 m wide, and up to 120 m long. The trenches begin at 2500 m elevation and progress up the side of a mountain and across a plateau with an elevation of 2835 m. Slope aspect is generally southeast.

METHODS

A reconnaissance was made in the summer of 1979, to gain familiarity with the flora and vegetation types of the study site. This reconnaissance indicated several vegetational variables to be considered during the course of the study. Undisturbed vegetation surrounding the trenches could easily be divided into two obvious categories: an unforested alpine area and a subalpine forest. Further variation of the subalpine forest was shown by the change in dominance from *Pinus contorta* at lower elevations, to *Abies lasiocarpa* and *Pinus albicaulis* at higher elevations, to dominance solely by *Pinus albicaulis* at the highest elevations.

Vegetation on disturbed trenches showed similar variation. There were several plants that were common on trenches in the alpine area and rare in the subalpine forest. Conversely, there were other plants common on trenches in the forest that were infrequent in the alpine. Also, *Pinus contorta* was restricted to the lower elevation trenches. A sampling plan was devised to elucidate this vegetational pattern, and also to demonstrate any possible correlation between the species composition of a particular trench and the species composition of undisturbed vegetation surrounding that trench.

Sample plots in the undisturbed vegetation were evenly distributed around and between the trenches (Figure 2). Plots were therefore situated so as to demonstrate the vegetation types that may be influencing colonization. The sampling method used was the releve method of the Zurich-Montpelier school of phytosociology (Becking 1957, Meuller-Dumbois and Ellenberg 1974). This method uses sample plots that require the following: 1) Plots are variable in size, but large enough to contain most species belonging to the plant community as defined by the minimal species/area criterion; 2) The habitat is uniform within the plot; and 3) The plant cover is homogeneous within the plot. After the releve was established, species were listed by tree, shrub, and herb layers. Categorical visual estimates of cover-abundance were then made for each taxon. These estimates have not only been proven effective through utilization by the releve method (Whittaker 1962), but also by Lyon (1968) who tested various methods of sampling shrub density (roughly analogous to cover-abundance) on a plot with a known number of shrubs. He concluded that:

> "...the most reliable density methods tested require a virtually prohibitive sample to attain barely acceptable precision for a statistical test which may fail to detect density differences that are probably obvious on visual inspection... it appears that categorical visual estimates or ranking might be just as reliable as more objective samples."

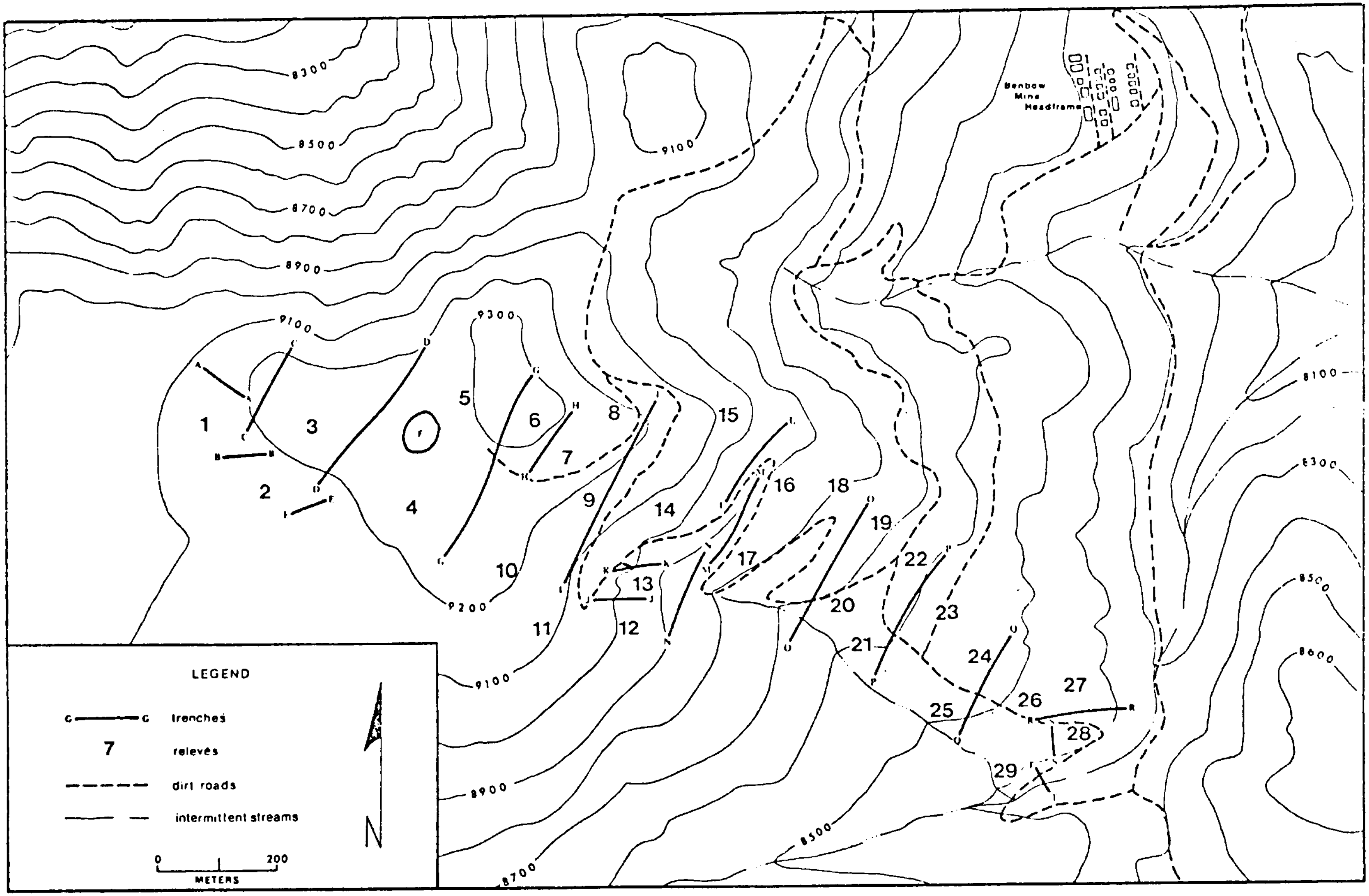
Trenches were sampled with a slight modification of the releve method. Each trench was considered as a single sample plot since its area was small and easily defined.

The cover-abundance scale used during releve sampling was modified from the Braun-Blanquet (1965) scale. Reconnaissance of the trenches indicated that more discrimination was needed in the lower end of the scale where plants were abundant but had low cover. The resulting scale is:

7 - Any number of plants, 75 to 100% cover
6 - Any number of plants, 50 to 75% cover
5 - Any number of plants, 25 to 50% cover
4 - Any number of plants, 10 to 25% cover
3 - Any number of plants, 5 to 10% cover
2 - Any number of plants, 1 to 5% cover

FIGURE 2

STUDY SITE SHOWING LOCATION OF TRENCHES AND RELEVES



1 - Abundant, but with low cover
+ - Scattered
r - Solitary or rare

Trees were aged on two of the lower trenches to determine whether colonization was episodic or an ongoing process. *Pinus contorta* was used since it is the dominant colonizer of the lower trenches, and the age of each tree was easy to determine. Trees were aged by counting the number of internodes on the main stem. To substantiate this method, trees of varying ages were cut and growth rings were counted. If a tree was damaged and its age was not easily determined, it was not sampled.

Voucher specimens were collected of all taxa found on sample plots. Identifications were made using local and regional floras (Hitchcock and Chase 1950, Hitchcock et al 1964, Booth and Wright 1966, Hahn 1977, Hermann 1970). Identifications were verified, and specimens deposited at Humboldt State University Herbarium (HSC).

RESULTS

Tabular analysis (Meuller-Dumbois and Ellenberg 1974) of the data from sampling the undisturbed vegetation indicated that there are four distinct habitat types in this study, a dry alpine habitat type and three forest habitat types. This conclusion agrees with classifications developed by Pfister et al (1977) and South et al (1971).

Pfister compiled a comprehensive classification of the forest habitat types in Montana. Application of this classification to the study area was quite effective. The forest habitats were readily identified using the keys and descriptions. According to this system, the forested areas in this study represent three of the upper subalpine habitat types of the *Abies lasiocarpa* series. The most abundant habitat type is the *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* (Abla-Pial/Vasc) habitat type, which surrounds a majority of the trenches.

The Abla-Pial/Vasc habitat type is characterized by *Abies lasiocarpa* as the indicated climax dominant; *Pinus albicaulis* as a long-lived seral dominant; *Picea engelmannii* as a codominant on more moist sites; *Pinus contorta* as a major seral species at lower elevations; and *Vaccinium scoparium* as a dominant in the undergrowth. Once disturbed, regeneration is expected to be difficult, and growth will be slow for this habitat type (Pfister et al 1977).

The other two forest habitats are both timberline types, the *Pinus albicaulis* (Pial), and the *Pinus albicaulis-Abies lasiocarpa* (Pial-Abla) habitat types. Both of these habitat types are classified by the dominant tree species only, since the understory vegetation can be quite variable. Common trees, in order of importance, are *Pinus albicaulis, Picea engelmannii,* and *Abies lasiocarpa*. The Pial-Abla habitat type differs from the Pial in that it more often assumes the krummholz shape, and has greater accumulations of snow. Regeneration of this habitat type is also considered to be very slow, and in some cases disturbances may be permanent if they are not rehabilitated (Willard and Marr 1971, Habeck 1972, Klock 1973, Pfister et al 1977).

South et al (1971) describe two similar forests, classified as a "subalpine forest ecosystem" and a "krummholz ecosystem." The subalpine forest ecosystem is equivalent to the Abla-Pial/Vasc habitat type. The krummholz ecosystem best coincides with the Pial-Abla habitat type. South describes the timberline habitats as having an understory similar to that of the nearby alpine vegetation. This contention is supported by my data.

Unforested alpine areas are not covered by Pfister's classification. The alpine area in this study is similar to South's description of a "dry alpine ecosystem." Characteristic vegetation is composed of low growing cushion and turf-forming plants. Again, re-establishment of vegetative cover after disturbance is expected to be very slow (Brown et al 1976, Brown et al 1978, Brown and Johnston 1978, Billings 1979).

Data collected while sampling the trenches indicates a definite correlation between the colonizing species and the surrounding habitat type. There are a few plants that are found colonizing nearly every trench regardless of the surrounding vegetation, there are some plants that are mostly confined to colonizing trenches surrounded by Abla-Pial/Vasc habitat type, and there are several other plants that mainly colonize the trenches surrounded by the alpine and timberline habitat types. There is some variation in colonization among the Pial, Pial-Abla, and the dry alpine habitat types, but it is slight in comparison to the difference between the Abla-Pial/Vasc and the other habitat types.

The sampling method used worked very well for the determination of plant cover found on the trenches. The modified cover-abundance scale gave needed emphasis to small herbs that were abundant but had low cover.

Using each trench as a single sample plot provided some assurance that scattered and/or rare plants were consistently found and reported.

Both of the trenches sampled for tree colonization showed that trees began establishing themselves immediately following disturbance. The number of trees in each age class decreases with increasing age since reclamation. The maximum number of trees were in the one year age class. Colonization has occurred each year, and presumably will continue to do so (Figure 3).

DISCUSSION

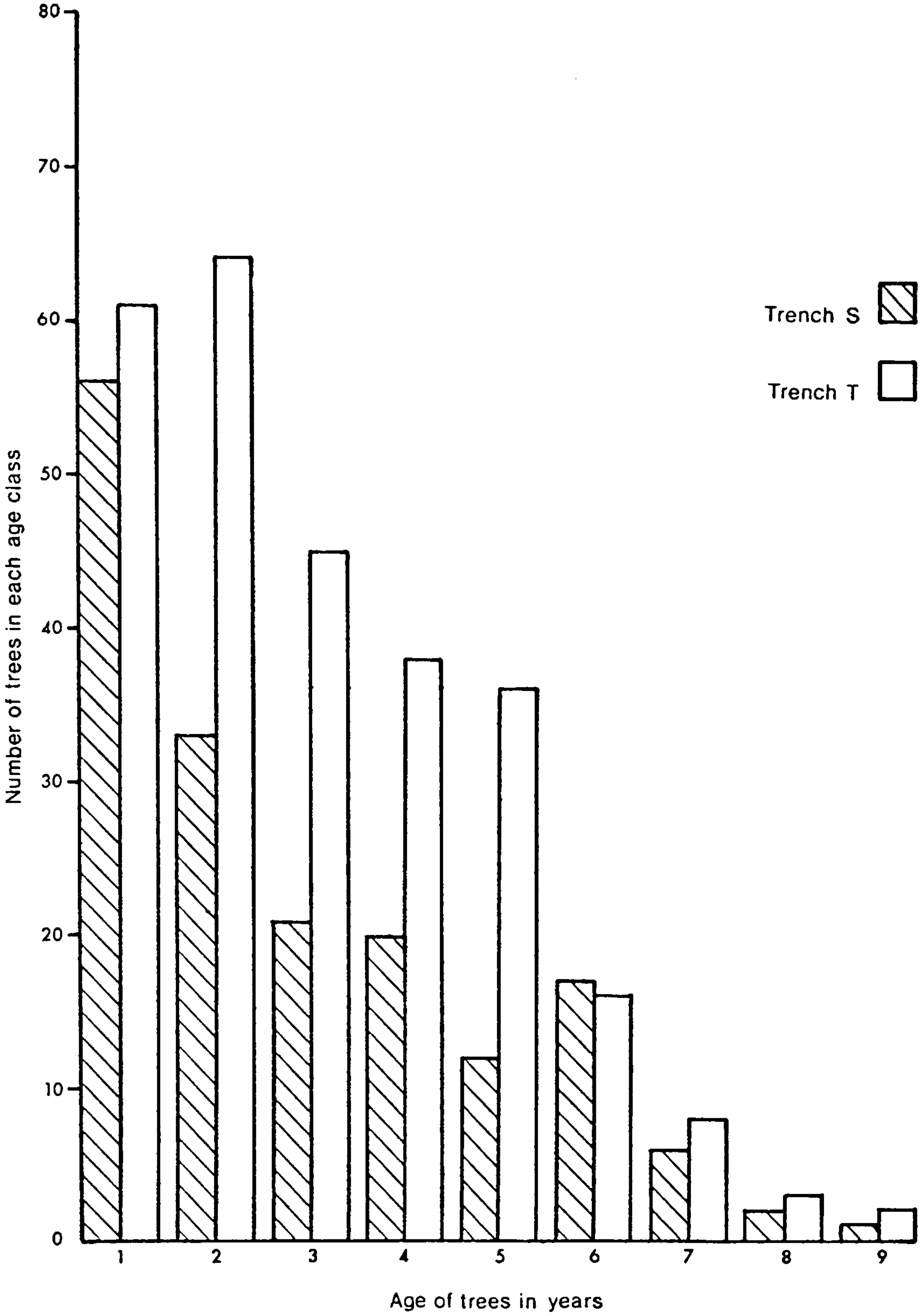
Colonization of *Pinus contorta* on the lower trenches suggests that there is no problem establishing native vegetation. Environmental conditions have been suitable for the establishment of trees each year for the past nine years since disturbance. From the number and abundance of species present on the trenches, it is safe to asume that environmental conditions have not been limiting the establishment of herbs either. Therefore, the limiting factor to colonization appears to have been the availability and dispersal of seed from the surrounding vegetation. Sowing adapted native seed during reclamation should mitigate the effect of this limiting factor.

The best adapted species for planting on the trenches are the most active colonizers on the disturbed areas. Seeding recommendations for revegetating the trenches should involve two different mixtures. There should be one mixture for use on the trenches surrounded by the Abla-Pial/Vasc habitat type, and another mixture for use on the trenches surrounded by the treeline and dry alpine habitat types. There are differences in colonization between the Pial, the Pial-Abla, and the dry alpine habitat types, but the differences are slight. The areas to be seeded are also small enough, so that using different seed mixtures would not be practical.

The species selected for revegetating the exploration trenches were chosen for their high frequency and high cover-abundance values on the trenches. Ease of collection was also taken into consideration when making the recommendations listed in Table 1. Planting these naturally occurring pioneer species should establish a self-sustaining vegetative cover that is successional to the surrounding vegetation types.

FIGURE 3

NUMBER AND AGE OF *PINUS CONTORTA* COLONIZING ON TWO OF THE LOWER TRENCHES



The undisturbed vegetation on the area of study is typical of the regional pattern of vegetation. The same habitat types are found in other mountainous areas of Montana, and perhaps throughout the northern Rocky Mountains according to Pfister (1977) who developed a comprehensive classification scheme for the forest habitat types found in Montana. These reoccurring habitat types are based on the climax vegetation type, and are easily recognizable and identifiable, even seral stages. Colonization of disturbances in the forest by native plants is directly correlated to the surrounding habitat type. Therefore it should be possible to conduct similar studies in other habitat types to arrive at a list of native species that are adapted for revegetating disturbed areas in any of the habitat types found in the State of Montana. Once these lists have been compiled, work can begin toward making these adapted native plants more readily available on the commercial market. Then reclamation work can get away from the use of ineffective exotic species, end turn toward a more effective program of natural revegetation.

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TABLE 1

SPECIES RECOMMENDED FOR REVEGETATING THE BENBOW TRENCHES BASED ON HIGH FREQUENCY AND COVER-ABUNDANCE VALUES FOR COLONIZERS

ALPINE MIXTURE (Pial, Pial-Abla, dry alpine)	SUBALPINE MIXTURE (Abla-Pial/Vasc)
Grasses	Graminoids
X Agrositanion saxicola	Carex phaeocephala
Calamagrostis purpurascens	Phleum alpinum
Poa interior	Sitanion hystrix
Herbs	Herbs
Antennaria umbrinella	Achillea millefolium
Campanula rotundifolia	Aster foliaceus
Geum rossii	Campanula rotundifolia
Lupinus leucophyllus	Epilobium angustifolium
Polygonum bistortoides	Lupinus leucophyllus
Senecio canus	Microceris nigrescens
Solidago multiradiata	Polygonum bistortoides
	Senecio canus
	Senecio pauperculus
	Solidago multiradiata
Shrubs	Shrubs and Trees
Artemisia campestris ssp. borealis	Pinus albicaulis
Potentilla fruticosa	Pinus contorta
	Potentilla fruticosa

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NORTHEASTERN BRITISH COLUMBIA -
PREPLANNING AND RECLAMATION OF EXPLORATION ACTIVITIES

by

R.E. Shields
and
D.G.S. Johnson
Denison Mines Ltd.
Coal Division
Vancouver, B.C.

NORTHEASTERN BRITISH COLUMBIA - PREPLANNING AND RECLAMATION OF EXPLORATION ACTIVITIES

ABSTRACT

The prime areas for coal exploration are usually alpine or subalpine environments, although some potential mine areas and access are in boreal, coniferous forests. To minimize environmental damage, pre-planning of access and exploration investigations is a requirement.

Road locations are initially located using air photographs, topographic maps and geologic maps. Potential problem areas are delineated and sources for road fill determined. In the field the planned road location is traversed and on site changes made. During road construction a concurrent reclamation program is maintained.

Once a preferred adit location is determined, access and exact seam location must be defined. Rotary drilling and geologic mapping along access trails aid in the seam definition. Use of existing access minimizes new environmental damage. Using a small backhoe can aid in seam exposure while lessening surface disturbance.

Following completion of the exploration program, all disturbed areas are reclaimed and access closed.

BACKGROUND AUTHORS

Dave Johnson, B.Sc., Mount Allison, has been involved in northeast coal exploration for the past three years and is presently the Project Geologist for Quintette.

Roger Shields, C.E.T., is a graduate of BCIT and has been involved in northeast coal exploration since 1970. He is presently the Field Manager for the Quintette project.

INTRODUCTION

The alpine, subalpine and boreal, coniferous forests that cover the coal measures of northeast British Columbia are undeniably one of the most scenic areas of this province. The alpine is reasonably accessible, the rivers have an abundance of fish and wildlife abounds. This may seem a bit flowery but the point is made. We appreciate this countryside. It is also our livelihood. We are concerned for both.

When planning an exploration program the objective is to produce the most amount of information for the least amount of dollars. This, however, must be balanced against environmental damage. By careful pre-planning and closely supervising its implementation, both of these objectives can be achieved.

LOCATION

The areas to be discussed in this paper are the inner foothills of northeast British Columbia.

Specifically, the discussion covers Quintette, Belcourt and Saxon projects. These properties range from the Alberta border to within 60 km of Chetwynd, B.C. The license area is in excess of 80,000 ha covering estimated coal reserves of over 4 billion tonnes.

ENVIRONMENT

The dominant surficial materials in high elevation areas are weathered and colluviated bedrock, and highly weathered tills deposited prior to the last glaciation. At lower elevations, the slopes of major valleys in western regions of the inner foothills region are covered by recent deposits of ground moraine which often extend to the valley floor. In the eastern portions of valleys, outwash deposits commonly replace or overlie the till. Other surficial materials present include small pockets of lacustrine materials overlying outwash, alluvial deposits in major valleys, and small organic deposits, mainly bogs.

The most common vegetation types are boreal and subalpine coniferous forests with alpine vegetation types at high elevations.

PLANNING

Pre-planning of roads, adits or even cat trails that may cause significant environmental damage is essential.

Initially topographic and geologic maps are examined. The geology and topography tells the planner the most likely location for a possible adit. This gives us an end point for our road location. Similarly, these maps will also help locate recessive and resistant formations. The recessive units tend to be wet and require excessive fill which in turn can result in slumping. The resistant units may require drilling and blasting or excessive fill to get around them. Knowing where the various problem lithologies are allows pre-planning around them while maintaining optimum grade.

The geologic knowledge of the area is also useful when searching for suitable road building material. For example, we knew that the Hulcross Formation, a marine siltstone/very fine sandstone, made a very good road bed for the relatively light equipment that would be travelling on it. Therefore, when planning we could pre-determine where possible borrow pits could be excavated without excessive surface disturbance. The road was planned to intersect this formation at several locations.

After examining the geologic/topographic maps, a more detailed examination is conducted with air photographs. This enabled us to locate prominent ridges, excessively wet areas, and slides. It is on the air photos that the preliminary road route and adit locations are indicated.

One of the most obvious reasons for planning is to use existing access. It makes sense both economically and environmentally. We have been fortunate in some of our exploration to have large, cleared seismic lines accessing some areas. Obviously, the seismic lines will not follow the best ground, but 90% of the time they are usable. Using tracked vehicles and wide pad caterpillar tractors, use of most of the trail is possible. And where it isn't, the seismic crews have usually constructed a bypass! However, it was necessary to corduroy in particularly wet areas.

In addition to seismic lines, we have used fire lines which have created access to recent burn areas. Keeping in mind the possible erosion problems, road locations in burn areas are preferable to those located in mature growth.

Finally, after determining as many routing options as possible, and comprising our drill and adit locations to expedite the program and minimizing environmental damage, we go to the field.

CONSTRUCTION AND CONCURRENT RECLAMATION

The first work to be performed is to cruise the proposed route. And to check the adit locations to ensure there really is coal there!

Cruising of seismic lines and existing trails is relatively easy. The problem areas are again noted on the air photos and we determine whether the route can be used, corduroying is necessary, or a bypass must be constructed.

Cruising virgin forest and undisturbed alpine areas is necessary to confirm the route chosen in the office. When checking the proposed route in the field, the target area, whether it be an adit location or drill hole site, is located first. This gives the individual locating the road a cursory examination of the potential road location. Then, working back from the objective along the available access, the road location is flagged.

Following this methodology, the road is located with an excellent knowledge of the terrain, resulting in the best possible routing.

Areas that are low lying, or crossing possible slide areas, are noted so that slashers and tractor operators can be advised. These people are shown the route and pre-slashing begins.

Pre-slashing of roadways through undisturbed mature forest minimizes hanging trees and allows them to be immediately brought to ground level. In this way, a minimum amount of damage is done to trees on either side of the roadway.

To reduce fire hazard and improve the aesthetic quality of the work, fallen trees are bucked into short lengths as well as buried once the tractor begins actual road making. Excessive slash along major roadways is piled and burned.

In areas of excessive cover, whether it be foliage or overburden, exact adit locations are difficult to find. For this reason, rotary drilling aids in drill hole location. Using the drill hole information to interpret the geology, and by careful examination of the topography, the suspected location of coal outcrop can be determined. The actual excavation of the coal seam is enhanced by the use of a small backhoe.

By cleaning the face of an adit in low relief areas with the backhoe, only a small area is required to clean the seam outcrop face. This definitely reduces the area damaged compared with that caused by a D-6 caterpillar.

In this way, the "search and destroy" method of seam outcrop is eliminated and environmental damage minimized.

Adit sites are located with drainage in mind, including proximity to major watercourses. Every attempt is made to ensure that water from the adit is restricted in its flow toward the drainage. This is often simplified by the distance. However, berms or ditches at a level below the portal are often used.

During construction the topsoil is set aside and a berm is placed around the adit platform to prevent coal spillage during the mining phase. The waste dump is located on a dry platform with berms and water diversion channels. Often, the adit platform is suitable for stockpiling the waste coal.

During all phases of construction close supervision is necessary to achieve the objectives of the pre-planning. This, of course, also applies to the reclamation.

RECLAMATION

Once adit construction is complete and the coal sample is taken, reclamation can begin.

The adit platform and drainage ditch are contoured to prevent erosion. The platform is used to pile waste coal and the coal is contoured against the highwall. The area is then covered by the soil set aside during construction. The area is seeded and fertilized with the appropriate mixtures as set down in the reclamation guidelines. The waste dump is treated in the same manner, ensuring water diversion channels are maintained to prevent erosion.

Since roads are often used from year to year in an exploration program, often only the ditches and embankments are seeded. Water barriers are used extensively to hinder erosion. Upon completion of a program, all roads are completely reclaimed by barriers, contouring where necessary, fertilizing, and seeding. Alpine areas in our Saxon property have had excellent success in road and drill site reclamation after several seasons of monitoring.

Drill sites along roads are recontoured and seeded. Generally little damage is done by the actual drilling process although the drill return is directed away from major watercourses and artesian holes are sealed by cementing. Since most diamond drill sites are helicopter supported, little environmental damage results. The areas cleared for these drill sites are slashed and bucked in a similar fashion to road construction. Reseeding is not usually required.

Trenches that have been dug on the property range from natural river cuts to hand trenches, to road cuts to deep backhoe trenches. Trenches that are dug are filled in and the larger backhoe trenches seeded. The amount of environmental damage by trenching is minimal, amounting to a total of 0.6 ha on Belcourt property over the past four years.

All work areas, whether trenches, drill sites or adit sites, are cleared of refuse during construction. This ongoing process, where a helicopter brings supplies and then removes the waste on the return trip maintains clean work areas. When necessary, we get the accountant out from behind his desk for garbage detail when large items such as empty fuel drums accumulate in the field.

The final reclamation is the refuse dump area, which is recontoured and seeded like any other excavation and, on program completion, the campsite is similarly treated.

FOLLOW-UP

In the initial years following reclamation, the site is revisited to monitor the progress of the reclamation. Reseeding may be called for. For example, Belcourt property which underwent its final year of exploration in 1980, will require seeding of the road crowns and reseeding of the areas that did not take because of an unusually dry spring and summer.

CONCLUSION

We consider that our methods of pre-planning, construction and reclamation have been successful in causing minimal disturbance, as well as speeding up the natural reclamation process.

EROSION CONTROL
IN THE QUEEN CHARLOTTE ISLANDS

by

W.W. Carr
Department of Soil Science, U.B.C.
and
C.J. Marchant
Botanical Gardens, U.B.C.

EROSION CONTROL IN THE QUEEN CHARLOTTE ISLANDS

INTRODUCTION

The Queen Charlotte Islands consist of approximately 150 islands, grouped into a triangular shape, that lie off the northwest coast of British Columbia (Calder and Taylor 1968). The Charlottes are approximately 250 km long and have a maximum width of 85 km. The two major islands are Graham and Moresby. The mountains of the Queen Charlotte Range form the backbone of the Islands with most peaks between 800 m and 1,100 m and a few above 1,300 m.

CLIMATE

The climate of the Charlottes can be summarized by this statement from Calder and Taylor's Flora of the Queen Charlotte Islands (1968):

> "The main distinguishing features of the climate of the Queen Charlotte Islands are the very cool summers, the very mild winters, the prevalence of cloudy skies and strong winds, and the excessive late fall and early winter precipitation."

The precipitation ranges from 1,550 mm per year on the east side of the Islands to in excess of 7,500 mm on the west coast. The average number of days per year with measurable precipitation ranges from 205 to 249. The 24-hour rainfall may be as high as 12 cm or 15 cm (Toews and Wilford 1978). It is this type of event that causes much of the problems associated with land instability.

VEGETATION

The Queen Charlotte Islands are within the Coastal Western Hemlock Biogeoclimatic Zone and the lower elevations are for the most part forested with commercial stands (Toews and Wilford 1978). These stands are composed of western hemlock, Sitka spruce, western red cedar, and yellow cedar. The forested lands are highly productive and still contain a high percentage of large old-growth timber. Forestry is only one of the main industries in the Charlottes, fishing is another.

FISHERY RESOURCE

All five species of Pacific salmonids and the steelhead trout occur in the Queen Charlottes. Approximate average annual escapements of the anadromous salmonids (the number of adult fish returning to spawning streams) are indicated in Table 1 for four watersheds on the south-eastern quarter of Graham Island (Toews and Wilford 1978). The Yakoun is the largest river in the Queen Charlottes and has an extremely high even year pink salmon run as well as providing spawning habitat for the only significant local Chinook salmon stock.

It has been noted that escapements of pink salmon were historically much higher than current levels (Toews and Wilford 1978). A decline in the quality and extent of spawning habitat due to forest harvesting practices is thought to be partially responsible for this decline (Toews and Wilford 1978).

THE PROBLEM

This decline in spawning habitat quality can be partially attributed to forest harvesting and road construction which can lead to an increased incidence of soil mass wasting in steep terrain (Rice et al 1972). Although there are numerous incidences of natural slope instability in the Charlottes, windthrow along clearcut boundaries, debris accumulation in gullies, and changes in drainage as a result of gouging during yarding have all been shown to contribute to accelerated mass wasting in clearcuts.

Forest roads have been recognized as a major source of sediment through both surface erosion and mass wasting. Road caused mass wasting is most often associated with inadequate or poorly maintained road drainage structures and overloaded fill/sidecast material. Surface erosion associated with forest roads may not be as spectacular as mass wasting but it can move large volumes of soil for up to 5 years after road construction (Rice et al 1972). In addition, all mass wasted sites are surface erosion sites following the initial soil movement.

THE CONFLICT

In August 1979, cutting permit #144 of Queen Charlotte Timber became the focal point of a clash between the fisheries and forestry industries.

TABLE 1

AVERAGE SALMONID ESCAPEMENT FROM 1966-1976

	RIVERS			
	Honna	Mamin	Tlell	Yakoun
Chum	4,800			
Coho	1,600	2,300	13,000	7,400
Pinks (even year)	18,700	40,000	6,200	348,000
Pinks (odd year)	500		4,000	800
Sockeye		200		11,000
Chinook				1,700
Steelhead		450		5,800

Federal Fisheries revoked their approval for logging in the Riley Creek watershed in Rennell Sound after the scale of mass soil movement was greater than anticipated. They issued a closure to further logging in an effort to prevent further damage to the spawning areas. However, the B.C. Ministry of Forests ordered the company to continue logging based on the initial approval from Federal Fisheries and the fact that over $2 million dollars had been invested in road development. The company followed the orders of the Ministry of Forests and the fallers were arrested by RCMP on charges laid by Federal Fisheries.

The resource conflict here and in other parts of the province is far from resolved, but it did serve to focus attention on the negative impact of some forest harvesting activities on the fishery resource. It also pointed out the lack of cooperation between the resource agencies involved.

THE EROSION CONTROL PROGRAM

In 1978, the B.C. Fish and Wildlife Branch requested the Ministry of Forests Research Branch to begin investigating methods of controlling erosion in the Charlottes. It was recognized that controlling surface erosion from roads and mass wasted areas would be an important step in alleviating the sediment problem. The re-establishment of vegetation on denuded slopes was chosen as the most effective and efficient method of achieving this goal.

Thus

> E.P. 834: The Rehabilitation of Severely Disturbed Forest Land

and

> E.P. 863: The Propagation of Native Shrub and Tree Species for Controlling Erosion

became involved in the Queen Charlotte Islands. E.P. 834 deals primarily with grass-legume establishment on denuded soil to control surface erosion and to aid in the return of this land to productive forest. E.P. 863 is concerned with the establishment of woody shrubs on disturbed sites to aid in surface erosion control, as well as enhancing slope stability through the development of a root network.

OBJECTIVES

1. Control of surface erosion from forest road slopes;

2. Control of surface erosion from mass wasted areas;

3. Enhancement of slope stability on mass wasted areas (or potentially unstable slopes) to prevent further slope degradation.

Objective 1:

Surface erosion control from forest road slopes can be accomplished through revegetation with grasses and legumes. Since most of the forest road slopes in the Charlottes are greater than 2:1 and receive rather high intensity rainfall, hydroseeding was deemed as the most practical method of slope revegetation.

Initial roadside seeding by the Research Branch in the Charlottes was very successful, even on some very steep cut and fill/sidecast slopes. Since these early efforts, the Research Branch has assisted MacMillan Bloedel, Crown Zellerbach, and Western Forest Products in the conversion of forest fire tankers into hydroseeders through the addition of a recycling agitation system. All three multi-purpose units will be in full operation in 1981.

Objective 2:

Once again, grass-legume establishment was chosen as the best method to halt surface erosion on these denuded slopes. However conventional application equipment could not begin to cover the types of slopes encountered. Dry-seed application by helicopter was disregarded due to its questionable success on steep slopes with high rainfall and strong winds. A better solution would be the application of a hydroseed slurry, containing seed, fertilizer, and a soil binder. The soil binder would hold the seed and fertilizer in place on the steep slopes until germination.

The first efforts at applying a hydroseed slurry to the slopes were with a Hughes 500 helicopter and a monsoon bucket. Although there was no agitation or gradual dispersion of the slurry to the slopes, these efforts were somewhat successful in establishing grass-legume cover on a portion of the slopes.

Over the winter 1980-81, Bill Marson (then Chief Engineer with Queen Charlotte Helicopters Ltd.) and Bill Carr (contractor with the B.C. Ministry of Forests) designed another method of spreading the slurry over the slope. Bill Marson built the new helicopter hydroseeder in the early spring of 1981 and this unit was operationally tested in May 1981.

The new seeder was a helicopter pod that could keep the slurry agitated and also apply it evenly over the slope. A 3 hp engine drives a central shaft which has an impellor inside the bucket for agitation, and a spreading disc underneath. Opening and closing of the drain port can be done electrically by the pilot. Although there are still some torque problems to be worked out, the unit was fairly easy to manoeuver and highly effective in covering the slope with the hydroseed slurry. The results so far have been very promising, with good vegetative establishment on some extremely steep sidewalls in the seeded gullies. The unit also proved to be very cost efficient. Tables 2, 3, and 4 provide a breakdown of the materials used and the costs incurred in the seeding of Crown Zellerbach Spur 29.

Future operations of this bucket are somewhat tenuous due to a change in the personnel and management of Queen Charlotte Helicopters Ltd., but we have devised a methodology for the seeding of previously inaccessible areas. The unit has proven to be fast and effective in the hydroseeding of steep slopes, as well as very cost efficient.

Objective 3:

Mass wasted slopes not only pose a serious surface erosion problem, but also remain unstable and are often subject to further soil movements until there is nothing left but bedrock. In this situation, the use of shrubs becomes an integral part of a revegetation program. The shrubs not only add diversity to the erosion control vegetation, but more importantly, they add a deep, strong root network. This root network has been shown to significantly increase the shear strength of soil (Endo and Tsuruta 1969, O'Loughlin 1972) as well as anchoring the soil mantle to more stable bedrock.

TABLE 2

HELICOPTER HYDROSEEDING: C-Z SPUR 29

General Information	
Total Area Seeded	3 hectares (approximately)
Total Slurry Applied	1,000 gallons
Total Materials Applied:	
Fertilizer (20-24-15)	450 kg
Seed Mix	100 kg
Soil Binder (Ecology M-1)	55 kg

TABLE 3

HELICOPTER HYDROSEEDING: C-Z SPUR 29

Flight Information	
Total Flight Time	1 hour
Average Payload	85 gallons
Number of Turns	12
Average Time Per Turn:	
Filling of Bucket	1.0 minute
Flight Time to Site	1.5 minutes
Spreading of Slurry	1.0 minute
Return Flight	1.5 minutes
Total	5.0 minutes

TABLE 4

HELICOPTER HYDROSEEDING: C-Z SPUR 29

Cost Breakdown

	Per Hour	Per Hectare
Helicopter Rental - Hughes 500 (including bucket)	$ 450	$150
Truck Hydroseeder (including labour)	300	100
Materials Applied:		
Seed Mix	275	92
Fertilizer	145	48
Soil Binder	290	97
Total	$1,460	$487

For the Queen Charlotte Islands, only native shrubs such as *Vaccinium ovatum*, *Rubus parviflorus*, and *Salix* sp. were considered for use because:

1. These native species are adapted to the local climate and soils;

2. There was great concern over the possible escape of an introduced species and the creation of a weed problem.

Table 5 provides a complete listing of the shrub species collected on the Charlottes for propagation. Hardwood cuttings, softwood cuttings, and seed were collected locally and transported to UBC for propagation. Shrub propagation methods and strategy are outlined in Appendix A.

As an example of our propagation methods, the following procedure for hardwood (dormant) cuttings is used. The cuttings are taken during the dormant season and shipped back to UBC. Upon arrival, they are trimmed to size (leaving 3 or 4 buds), dipped in root hormone, bundled in groups of 15, and placed in a cold-frame over winter. In the spring, rooted cuttings are lined out in the nursery field for "growing on."

The rooting results for the Queen Charlotte shrubs are given in Table 6. Both hardwood and softwood cuttings were for the most part very successful. If possible, hardwood cutting is the preferred method due to its simplicity and ease of handling. Softwood cuttings require much more attention and handling, including greenhouse facilities with a mist system. Our seed program is just getting under way and we have no tabulated data at this time. However, when dormancy and other technical problems are ironed out, seed propagation is likely to be the most operationally and cost efficient method for most species.

Last November, shrubs from 6 species were lifted from the nursery bed, transported back to the Charlottes, and planted at 4 test sites. For the most part we selected large rooted stock grown in beds, but did include some rooted willow sticks (*Salix* sp.) that were still in the cold-frame. Table 7 includes a list of the chosen species and the numbers planted.

Three of the test sites were V-notch gullies that had been hydroseeded in May 1980. The other site was a recent road failure that resulted

TABLE 5

SHRUBS COLLECTED FOR THE QUEEN CHARLOTTE ISLANDS

Species	Seed	Cuttings	
		Hardwood	Softwood
Sambucus racemosa	X		X
Symphoricarpos albus		X	X
Spirea douglasii	X	X	X
Rubus spectabilis		X	X
Rubus parviflorus			X
Cornus stolonifera		X	
Salix sp.		X	X
Rosa sp.	X	X	X
Vaccinium parviflorus	X		X

TABLE 6

ROOTING SUCCESS OF COLLECTED SHRUBS

Species	Cuttings	
	Hardwood	Softwood
Sambucus racemosa		98%
Symphoricarpos albus	90%	77%
Spirea douglasii	96%	95%
Rubus spectabilis	61%	88%
Rubus parviflorus		21%
Cornus stolonifera	63%	
Salix sp.	99%	99%
Rosa sp.	19%	79%
Vaccinium parviflorus		61%

TABLE 7

QUEEN CHARLOTTE FIELD TRIALS: NOVEMBER 20-21, 1980

Species Planted	Numbers
Symphoricarpos albus	96
Rubus parviflorus	73
Rubus spectabilis	118
Cornus stolonifera	50
Spirea douglasii	30
Salix spp.	
- Big stock	55
- Rooted stick	258
	680

from the overloading of the fill slope. Planting on the steeper slopes was much easier when there was a well established grass-legume cover. These areas were also subject to far less surface erosion, which on some non-grassed slopes exposed some of the shrubs' root systems. In one instance, at least 5 cm of soil eroded from a portion of an uncolonized part of a slope which totally uncovered some of the planted shrubs.

As of June 1981, the majority of the planted shrubs were growing well (Table 8). Although the numbers of some species are small, these preliminary results are very promising. Most shrubs were subjected to some degree of deer browse, but so far it has been a problem only with willow (*Salix* sp.). The large rooted stock appears to be able to tolerate low levels of browse activity.

TABLE 8

QUEEN CHARLOTTE FIELD TRIALS: SPECIES ESTABLISHMENT AS OF JUNE 3, 1981

Species Planted	Survival Percent
Symphoricarpos albus	99
Rubus parviflorus	60
Rubus spectabilis	100
*Cornus stolonifera	100
Spirea douglasii	100
Salix sp.	
- Big stock	100
- Rooted stick	55

6

APPENDIX A

SHRUB PROPAGATION METHODOLOGY AND STRATEGY
B.C. MINISTRY OF FORESTS #EP 863 - CHRIS MARCHANT

Objective: To control mass movement, soil creep, minor sheer failure, ravelling and to rehabilitate slopes through the use of live root systems of smaller woody plants.

Method depends on mechanical strength and on water absorptive capacity of the roots. Probably also depends on the development of ramifying subsurface water movement channels along these root systems.

Species Selection and Choice of Method for Each

There are about 50 potentially suitable native or naturalized species in B.C. (Table 9). Total studied to date in EP 863 is 30 species (Table 10). To each of these can be applied a set of considerations and parameters before outplanting on a site as follows:

1. Choice of Propagule Type (bare root or containerized)
   Depends on:
   - Site conditions (accessibility, etc.)
   - Soil conditions (degree of moisture)
   - Ravelling or slumping on slope.
   - Aspect (wind, sun, frost, etc.)
   - Steepness
   - Elevation
   - Regional occurrence
   - Availability at time of collection (e.g. seed source, location, collection and cleaning has to be timed for each species and elevation)

2. Size of propagule
   Similar consideration as in 1. above:
   - Economics of production, transportation
   - Speed of outplanting growth vs. percent survival
   - Relative ability to establish in a given site

3. Time of Outplanting in Field Plots

Dependent on:

- Season (snow melt date)
- Elevation
- Occurrence of highest and most destructive rainfall
- Periods and frosts (heaving)
- Availability of material
- Allowance of enough time for good root establishment before winter or before summer heat

4. Block Patterns and Spacing Arrangement

Trial and Error: Some logical application to slope mechanics or run-off characteristics. Spacing approximately 1 m but dependent on the species.

5. Monoculture Vs. Mixtures of Species

Attempt to predict the successional characteristics of the site. Assess the soil levels of a given site in which root development is required.

6. Engineering Influences

Road construction timing and cooperative effort (e.g. Rover Creek).
Road maintenance timing (clearing ditches, sidecasting etc.).
Log hauling (interfering with access to site or work on a roadside site).

7. Animal Browse

Determining the susceptibility of species to browse damage where game plentiful or overstocked (QCI).

Summary

Selection of best shrub species depends not only on field site performance but on ease of propagation and subsequent growth response + specific rehabilitation value.

e.g. *Symphoricarpos* vs. *Ceanothus*

Propagation Methods

Softwood cuttings		*Lonicera involucrata*
Hardwood cuttings	e.g.	*Cornus ceriseus*
Seed		*Philadelphus lewisii*
Offsets and layering		*Corylus cornuta*

Great variation in response and ease of application between species.

1. Methods - Hardwoods

Gathering strong dormant current year shoots, cutting, dipping, bundling, storing (sawdust, fridge) line-out next spring.

a. Advantages

Rapid growth once rooted (compared to some seed)
Avoids problems of seedling propagation (timing of stratification, etc.)

b. Drawbacks

Slow and unreliable with many species
Needs careful storage
Bulky collection and storage
Difficult to control water content during storage
Often difficult to find healthy and suitable material

2. Methods - Softwoods

Gathering from plump current year shoots without disease damage. Transfer to propagation facility. Cutting, dipping and inserting in medium under mist irrigation. To be done in summer when shrubs sufficiently grown and matured.

a. Advantages

Fast rooting (e.g. *Lonicera involucrata)*
Easy to monitor progress
Usually easy to find suitable field material (e.g. *Shepherdia canadensis)*

b. Disadvantages

Often short growth season (July to September)

Resulting young plants tend to have poor root development by the onset of winter - poor survival

Plants not large enough to outplant by the first fall (e.g. *Salix* from higher elevations)

Often deteriorates during transport from field material collection site to facility in summer

3. Methods - Offsets and Layering

Only usable for a few suitable species (e.g. *Corylus)*.

a. Disadvantages

Need to build stock plants at a nursery facility (layering)

Fairly slow process requiring field space

4. Root Cuttings

Labourious field collection

Slow results

Suitable for very few species (e.g. *Shepherdia)*.

5. Seed Propagation

a. Advantages

Generally most efficient process

Large stocks can be held in storage

Germination can be timed

Even-aged progeny develop with good form

b. Disadvantages

Location of abundant wild sources of wide range of provenances not easy

Stratification needed to break dormancy often complex and precise. Sometimes unknown (e.g. *Symphoricarpos)*.

Seedlings of some susceptible to damping off or "shock"

Sometimes seed almost impossible to collect (e.g. *Salix, Ceanothus)*

Sometimes large quantities of fruit yield few seeds *(Shepherdia)*

In conclusion, before there can be adequate field planting trials there must be successful propagation methods established. This is the key to a native shrub program and one upon which every applied effort is worthwhile.

Results at the end of this second year are very promising. Upwards of 7,000 propagules of 30 species are under development this fall. Planting trials will be expanded in QCI, the Fraser Canyon and West Kootenays.

The end product of the study will be publication of an established set of guidelines for shrub propagation methodology and for field utilization of native shrubs in soil rehabilitation.

TABLE 9

SPECIES RECOMMENDED FOR EROSION CONTROL AND THEIR SUCCESSFUL METHODS OF PROPAGATION

SPECIES	SEED		HARDWOOD		SOFTWOOD		ROOT OR OTHER	
Acer glabrum var. douglasii	/	-			/	-		
Alnus viridis ssp. sinuata	/	-						
Alnus incana ssp. tenuifolia	/	+?						
Amelanchier alnifolia	/	-						
Arctostaphylos uva-ursi	/	-						
Berberis aquifolium	/	+						
Betula lenta	/	+						
Betula papyrifera	/	+						
Betula pendula	/	+						
Betula sp.			/	-				
Ceanothus sanguineus	/	+?	/	p-	/	-		
Ceanothus velutinus								
Cornus sericeus	/	+	/	-				
Corylus cornuta			/	-				
Crataegus douglasii	/	+						
Gaultheria shallon								
Holodiscus discolor	/	+	/	p-	/	-		
Juniperus horizontalis			/	-				
Lonicera involucrata			/	-	/	+		
Pachistima myrsinites			/	-	/	+		
Philadelphus lewisii	/	-	/	p-	/	+		
Populus trichocarpa			/	-				
Physocarpus capitatus					/	-?		
Prunus virginiana var. demissa	/	+						
Prunus sp.			/	-				
Ribes laxiflorum					/	-		
Ribes sp.					/	-		
Shepherdia canadensis					/	+	/	-
Sambucus cerulea	/	p+			/	+?		
Sambucus racemosa var. arborescens								
S. racemosa var. melanocarpa	/				/	+		
Salix sp.			/	+	/	+		
Symphoricarpos albus	/		/	+				
Spiraea douglasii	/	+	/	+				
Rubus parviflorus	/	+	/	-				
Rubus spectabilis	/	+	/	-				
Rubus leucodermis	/		/	+				
Robinia pseudoacacia	/	+						

Method Tried: / = yes

Successful: + = yes; - = no; p = poor; +? = unsure; ? = unknown awaiting results.

TABLE 10

SHRUB AND TREE SPECIES TESTED, METHODS AND SITE PREFERENCES - SUMMARY - TENTATIVE

Species Name	Region: Coast/ Interior	Type of Rooting	Method of Propagation		Ease of Propagation	Suitable Outplanting Site	Cultivation Method Suited to Outplanting
			Cutting	Seed			
Salix ssp.	Both	Deep	S H	X	Moderate	Moist to Wet	Container or Stick
Populus trichocarpa	Both	Deep	H	X	Good	Moist to Wet	Container or Stick
Betula papyrifera	Interior	Moderate to Deep	X X	S	Good	Dry to Moist	Container or Bare Root
Alnus incana ssp.	Interior	Deep	X X	S	Moderate	Moist to Wet	Container
Alnus viridis ssp. sinuata	Interior	Deep	X X	S		Moist to Wet	Container
Cornus sericeus	Both	Fibrous	H	S	Easy	Moist to Wet	Bare Root
Amelanchier alnifol.	Both	Moderate to Deep	XXX	S	Fair	Dry, Rocky	Container
Acer glabrum var. douglasii	Interior to Coastal	Deep	L	S	Fair	Dry to Moist Rocky	Container
A. circinnatum	Coastal, southern	Moderate	XXX	S	Fair	Moist	Container
Sambucus racemosa var. arborescens	Coastal	Moderate	S.	S.	Fair	Moist	Container
Sambucus racemosa var. melanocarpa	Interior	Moderate		S		Moist	Container
Sambucus cerulea	Interior	Moderate		S	Fair	Moist	Container
Physocarpus capitata	Both			S	Good	Dry to Moist	
Prunus virginiana	Both	Moderate	XXX	S	Moderate	Dry-Moist	Container or Bare Root
Prunus emarginata	Both	Moderate	XXX	S	Moderate	Dry-Moist	Container or Bare Root
Crataegus douglasii	Interior and Coast		XX	S	Good	Dry	Container
Crataegus columbiana	Interior			S		Dry	Container
Ceanothus sanguineus	Both	Deep	XXX	S	Poor	Dry	Container
C. vellutinus	Interior	Deep	XXX	S	Poor	Dry	Container
Spiraea douglasii	Coast	Shallow, rhizomes	SLH	S	Easy	Moist to Wet	Container or Bare Root

TABLE 10 (Continued)

Species Name	Region: Coast/ Interior	Type of Rooting	Method of Propagation Cutting	Seed	Ease of Propagation	Suitable Outplanting Site	Cultivation Method Suited to Outplanting
S. betulifolia	Interior	Shallow+ rhizomes	H	S		Dry	Container
S. densiflora	Interior Montane						
Mahonia aquifolium	Coast to Interior	Shallow, rhizomes		S	Moderate	Dry, Rocky	Container
M. nervosa	Both	Shallow, rhizomes		S	Moderate	Moist, Shady	Container
M. repens							
Lonicera involucrata	Both	Moderate	S H	S	Easy	Dry to Moist	Container or Bare
Symphoricarpos albus	Both	Shallow+ rhizomes	S H	S	Easy, Seed Slow	Dry to Moist	Container or Bare
S. mollis							
Viburnum edule							
Ribes lacustre	Both	Fibrous	S	S		Moist to Wet	
Ribes sanguineum	Both	Fibrous		S		Dryish to Moist or Shade	
Ribes lobbii	Coast						
Ribes cereum	Interior			S		Dryish	
Ribes viscosissimum	Interior			S		Dry-Moist	
Rubus spectabilis	Coast	Moderate and rhizomes	X X	A	Good	Moist to Wet	Container or Bare Root
Rubus parviflorus	Coast and Interior	Moderate	X X	S		Moist	
Rubus leucodermis	Both	Moderate	L	S	Good	Moist	Container or Bare Root
Vaccinium membranaceum	Both	Shallow		S	Fair	Dry to Moist	Container
Vaccinium ovalifolium	Coast	Moderate	S H	S	Fair	Moist	Container
Vaccinium parvifolium	Coast	Moderate	S H	S	Fair	Moist	Container
Arctostaphylos uva-ursi	Both	Shallow		S	Fair	Dry	Container

TABLE 10 (Continued)

Species Name	Region: Coast/ Interior	Type of Rooting	Method of Propagation		Ease of Propagation	Suitable Outplanting Site	Cultivation Method Suited to Outplanting
			Cutting	Seed			
Gaultheria shallon	Coast	Moderate		S	Easy	Moist to Wet	Container
Shepherdia canadensis	Interior	Deep	S X	S	Difficult	Dry to Moist	Container
Holodiscus discolor	Both	Moderate	X H	S	Moderate	Dry to Moist	Container
Philadelphus lewisii	Interior	Moderate	H	S	Good	Dry	Container
Robinia pseudoacacia*	Both	Deep	X X	S	Good	Dry to Moist	Container
Eleagnus commutata	Interior	Deep		S		Dry	Container
Total: 47							

Note:

1. 29 tried to date; these marked -
2. * = naturalized

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EVALUATION AND SELECTION OF NATIVE WOODY PLANTS FOR RECLAMATION IN THE EASTERN SLOPES OF ALBERTA

by

P.J. King and W.B. Russell
Reforestation and Reclamation Branch
Alberta Forest Service
Department of Energy and Natural Resources
Edmonton, Alberta

G. Grainger and A. Straka
Alberta Tree Nursery and Horticultural Centre
Alberta Agriculture
Oliver, Alberta

EVALUATION AND SELECTION OF NATIVE WOODY PLANTS FOR RECLAMATION IN THE EASTERN SLOPES OF ALBERTA

ABSTRACT

Native trees and shrubs offer advantages for use in reclaiming to land uses such as timber production, wildlife habitat, slope stabilization, and recreational use. However, lack of specific information on their ecological requirements, propagation, and outplanting performance has restricted their use in reclamation to date in the Eastern Slopes of Alberta.

This program is designed to address such restrictions to operational woody plant use. It is to examine site requirements for the twenty-four candidate woody plant species, identify and test their required germination pre-treatments (for seed propagation), field test the species in the Eastern Slopes region, and formulate prescriptions for their establishment and maintenance.

For the candidate species the results of the program to date are presented. These include the summary of an ecological field survey and review, a land use matrix, seed collection guidelines, summary of a seed pre-treatment review, and the findings which have been completed to date of a seed testing project for difficult-to-germinate candidate species.

The general objectives of future work in the program are also discussed.

INTRODUCTION

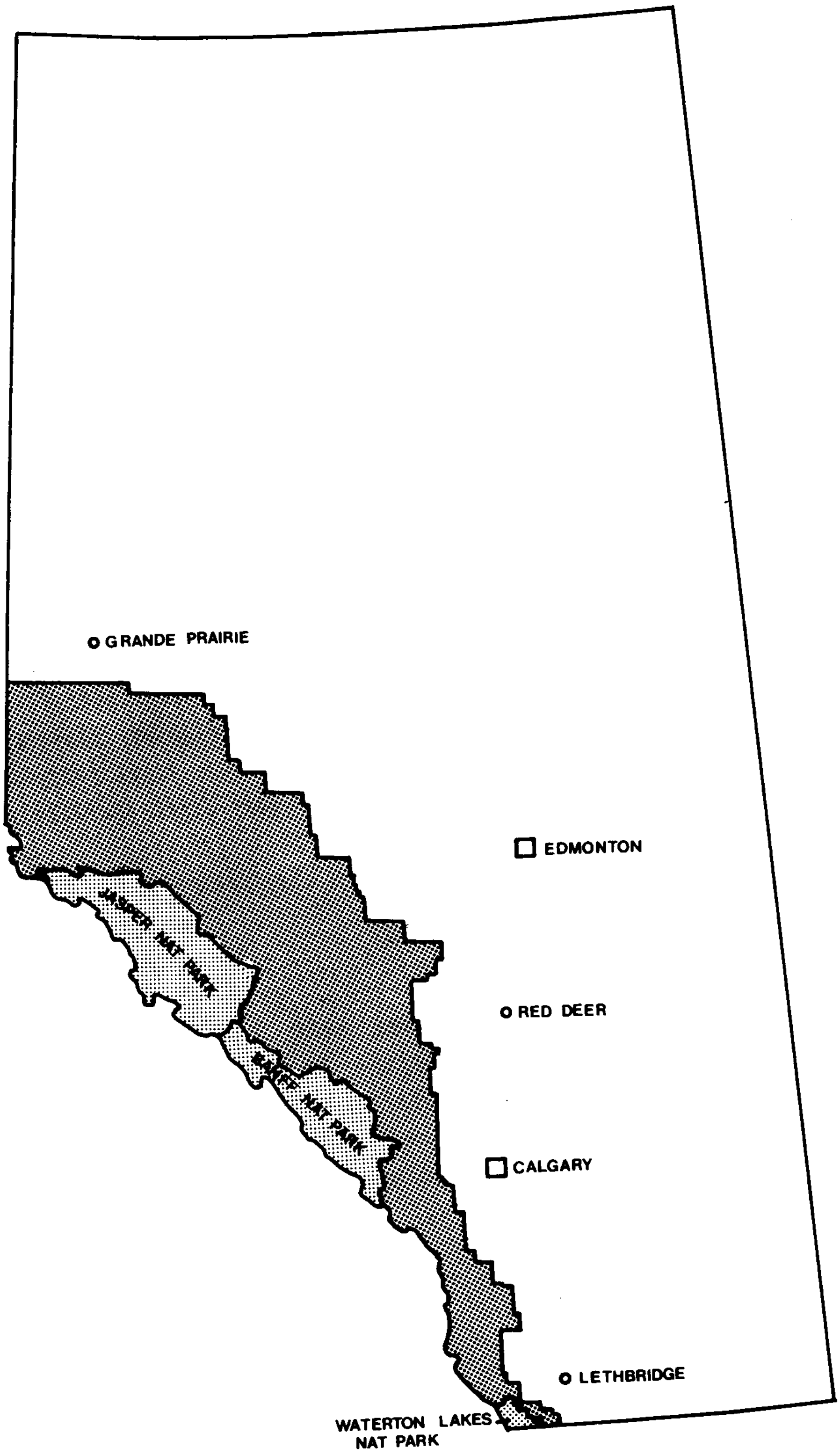
To date native woody plant species have been underutilized in the reclamation of disturbed sites on the Eastern Slopes of Alberta. We presently lack both a coherent experimental data base on many species and direct experience in their use for reclamation. A programme was established to address these deficiencies for a number of native trees and shrubs.

DESCRIPTION OF THE STUDY AREA

The Eastern Slopes region of Alberta, illustrated in Figure 1, occupies approximately 90,650 km^2 of the Rocky Mountains and Rocky Mountain Foothills. The climatic regimes of the area are characterized variously

FIGURE 1

THE ALBERTA EASTERN SLOPES



as Cordilleran and Boreal. Vegetation regions include the fescue grass, aspen parkland, subalpine, montane alpine, boreal foothills, and boreal uplands associations. Important land uses involve both renewable (water, timber, range, wildlife, recreation) and non-renewable (coal, oil and natural gas) resources.

The primary objective in land reclamation in the area is to ensure that all disturbed land will be returned to a state which will be as productive or useful to man at least to the degree it was prior to being disturbed.

THE NATIVE WOODY PLANT PROGRAMME

The programme's candidate native tree and shrub species are listed below:

Table 1
List of Candidate Woody Plant Species for Reclamation on the Eastern Slopes of Alberta

SCIENTIFIC NAME	
Alnus crispa (Ait.) Pursh.	green alder
Alnus tenuifolia Nutt.	thin leaf alder
Amelanchier alnifolia Nutt.	Saskatoon
Arctostaphylos uva-ursi (L.) Spreng	bearberry
Cornus stolonifera Michx.	red osier, dogwood
Elaeagnus commutata Bernh.	silverberry
Juniperus communis L.	ground juniper
Larix lyallii Parl.	alpine larch
Pinus flexilis James	limber pine
Populus balsamifera L.	balsam poplar
Populus tremuloides Michx.	trembling aspen
Potentilla fruticosa L.	shrubby cinquefoil
Rosa acicularis Lindl.	prickly rose
Rosa woodsii Fendl.	Fendler woods rose
Rubus parviflorus Nutt.	salmonberry
Rubus strigosus Michx.	wild red raspberry
Salix barrattiana Hook.	willow
Salix bebbiana Sarg.	beaked willow, bebb willow
Salix glauca L.	grey willow
Salix planifolia Pursh.	willow
Salix scouleriana Barratt.	scouler willow, black willow
Shepherdia canadensis (L.) Nutt.	russet buffaloberry
Sorbus scopulina Greene	Green's mountain ash
Sorbus sitchensis Roemer	sitka mountain ash

The overall scope of the evaluation and selection programme is given in Figure 2.

The evaluation phase utilizes the following criteria to reduce the number of candidate species into a short list:

1. Value in restoring mined or disturbed land to a productive, renewable land use.

2. Adaptability to sites which have been disturbed.

3. Ability to ameliorate disturbed land.

4. Ability to naturally increase or maintain itself.

5. Feasibility of large scale nursery or greenhouse propagation from seed.

The secondary objective of the evaluation phase is definition of site requirements for the various species and determination of the major limitations to their use in reclamation. Evaluation is based on review of currently available information and original research.

After the short list has been completed the process of establishing field trials will begin. The short list will be finished late in 1981 with the field trials being scheduled for planting in the spring of 1983.

Programme completion is expected in 1993.

EXAMPLES OF THE EVALUATION PROCESS

To illustrate the evaluation procedure being used, two of the candidate species are discussed. The first example demonstrates how the role of one candidate species in land reclamation was defined. The second example shows how a potential difficulty with an otherwise promising candidate species was addressed.

FIGURE 2

SCHEMATIC OF THE EASTERN SLOPE NATIVE WOODY PLANT PROGRAM

CANDIDATE LIST

↓

EVALUATION

1. Ecological Survey and Review
2. Land Use Review
3. Propagation Review and Testing

↓

SHORT LIST

↓

ADAPTABILITY TESTING

↙ ↘

<u>SELECTION</u>

<u>PRESCRIPTION FORMULATION</u>

EXAMPLE I: LIMBER PINE (Pinus flexilis James)

Limber pine is a small-to-medium sized tree (7.0 m to 15.0 m) of variable form. On sheltered sites it may be well formed while in exposed situations it is often multiple-stemmed and stunted.

It is primarily a montane species but may occur in the subalpine. Latitudinal limits in Alberta are 49 to 52°N while its altitudinal range extends from 925 m to 1,825 m asl (el.).

Land Use

The value of limber pine for various land uses is summarized in Table 2. Those uses of greatest value include erosion control and watershed protection and wildlife management for mountain goat and for various species of small game.

Adaptability of Disturbance

Limber pine is adapted to disturbance. In a field survey carried out by the Alberta Forest Service it was found on 10% of the disturbed sites examined in the southern portion of the study area (Russell 1979). It is often the primary tree species to establish in grassed, montane sites (Woodmansee 1972). Throughout its range in the United States it is characteristic of erosively disturbed sites where there is a low density of grasses and herbs (Lepper 1974). Establishment may also be successful on burned areas (King 1967).

Amelioration Value

The species has relatively little ability to ameliorate disturbed land. However, it is considered to be a critical protection species on steep slopes endangered by erosion (Steinhoff 1972) and thus may prevent extreme site degradation due to this source.

Ability to Maintain/Increase

The ability of a species to naturally maintain itself or increase in abundance is a function of its competitive ability, mechanisms of natural reproduction, and longevity.

TABLE 2

SUMMARY OF INFORMATION ON LIMBER PINE LAND USE VALUE/POTENTIAL

				WILDLIFE						
Erosion Control	Watershed	Forestry	Livestock Range	White-Tailed Deer	Mule Deer	Elk	Moose	Bighorn Sheep	Mountain Goat	Other
very valuable	very valuable	low value; some use for posts and timber	low value	no information	low palatability; winter use; some use during remainder of year	low palatability; some fall use	no information	low palatability; some use	highly palatable; winter use; some spring and summer use	porcupine, grouse, squirrel

Limber pine has a moderate competitive ability. On mesic sites it cannot compete with other tree species. However, in more xeric situations it may form the physiographic climax (Booth 1950, Kojima 1980).

Natural reproduction is by seed. Birds and rodents are critical dispersal vectors (King 1967, Woodmansee 1977).

Limber pine is very long lived. Tree ages 150 to 250 years are not uncommon (King 1967, Lepper 1974). Ages of 422 to 1,200 years have been recorded (Ibid).

In summary, the species can be expected to maintain itself on sites with low soil moisture. However, on other areas it likely would be replaced eventually by other woody vegetation. The rate of limber pine increase would not be expected to be rapid.

Propagation from Seed

Limber pine can feasibly be grown in large quantities from seed. Table 3 summarizes the information on the species' need for germination pretreatments. The species is mildly dormant and requires cold stratification for 20 to 60 days.

Species' Requirements and Limitations: A summary of the autecological information available for this species is presented in Table 4. Limber pine has potential for use in reclamation of extremely harsh sites and for extension in range beyond those areas where it occurs naturally. Major limitations to its use would include excessive soil moisture, high total soluble soil salts, white pine blister rust, and mountain pine bettle.

EXAMPLE II: SILVERBERRY (Elaeagnus commutata Bernh.)

Silverberry is an intermediate sized shrub of up to 4 m in height. It is found throughout the Eastern Slopes study area to an elevation of approximately 1,525 m asl.

Land Use

The land use information on silverberry is presented in Table 5. Its major potential uses include erosion control and watershed protection and wildlife management for elk, moose, mountain goat, and small game.

TABLE 3

SUMMARY OF REVIEW ON GERMINATION PRETREATMENTS FOR LIMBER PINE (FROM: KING, 1980)

Reference	Germination Pretreatment(s)	% Germ Obtained	Location	Researcher's Comments
Anon., 1966	cold stratification at 3°C to 5°C for 21 days		not applicable	
Anon., 1978	cold stratification at 3°C to 5°C for 21 days		not applicable	optimum germination conditions are an alternating 20-30°C temperature (8 and 16 hour cycles respectively) without light
Babb, 1957	cold stratification at 41°F (5°C) for 30 days		not applicable	
Chadwick, 1935	cold stratification at 41°F (5°C) for 30 to 60 days (in moist acid peat)		none given	
DenHeyer, per. com.	cold stratification at 5°C for 2 months		Alberta	
Heit, 1968a; Heit, 1973	cold stratification at 36°F to 40°F (2.2°C to 4.4°C) for 20 to 30 days		Wyoming, Colorado, New Mexico	species exhibits a mild embryonic dormancy
Lepper, 1974	cold stratification at 5°C to 7°C for 14 days	95, 43, 15, 40 (4 lots)	California, Wyoming	optimum germination conditions are an alternating 5-13°C temperature (12 hour cycles) without light
Lohmiller, per. com.	cold stratification at 33°F to 38°F (0.6°C to 3.3°C) for 20 days		Montana	
Stark, 1966	brief period of cold stratification required		Nevada	
Swingle, 1935	cold stratification at 32°F to 50°F (0°C to 10°C) for 30 to 60 days	80	none given	

TABLE 4

SUMMARY OF AUTECOLOGICAL INFORMATION ON LIMBER PINE

Eastern Slope Distribution			Soils													
"Eco-region"	Alti-tudinal Range (m asl)	Lati-tudinal Range (*)	Parent Material	Soils Order	Depth (cm)	Texture	pH	Organic Matter/ Nutrients	Moisture	Drainage	Other	Drought Tolerance	Slope	Aspect	Insects	Diseases
montane; rare occur-rence in sub-alpine	925-1825	49-52 N	wide range of parent materials including sandstone, limestone, dolomite, alluvium	regosols	0-75	CL, L, LS, SL, soils often very stony	5.9-7.7	tolerant of soils with low organic matter and low nitrogen	very dry-moist	exces-sively well drained to well drained	low toler-ance to salts	very tolerant	flat-very steep	all; in Alberta forms climax on south aspects	19 on species; that of major concern is _Den-droctonus ponderosae_ (mountain pine bettle)	9 on species in Alberta; that of major concern is _Cronartium ribicola_ (white pine blister rust); limber pine is moderately suscep-tible to this rust

TABLE 5

SUMMARY OF INFORMATION ON SILVERBERRY LAND USE VALUE/POTENTIAL

				WILDLIFE						
Erosion Control	Water-shed	Forestry	Livestock Range	White-Tailed Deer	Mule Deer	Elk	Moose	Bighorn Sheep	Mountain Goat	Other
very valuable	very valuable	no direct value; may be of use for site ameliora-tion in Forestry	low value; fruit may be eaten by live-stock; use on livestock range may create a barrier to grazing	low palata-bility; little use	low palata-bility; light use	moderate-high pala-tability; principally winter use; may get some use during other periods of year	moderate palata-bility; winter use	low palata-bility; little use	highly palatable; winter use; some spring use	snowshoe hare; ringnecked pheasant; grouse

Adaptability to Disturbance

The species is highly adapted to disturbance. In Alberta it is primarily a species of disturbed habitats (Moore 1964). It is frequently found on such disturbances as erosion gullies and slopes, river edges and cliffs, land slides, and roadcuts. The A.F.S. field survey found it on 8% of the disturbed sites examined in the study area (Russell 1979).

Ameliorative Value

Silverberry is valuable for the amelioration of disturbed sites. It is an important grassland nitrogen-fixer (Vlassak 1973). In one study, the annual nitrogen contribution from silverberry leaves was estimated to be 38 kg/ha N (Whysong and Bailey 1975). Innoculation of silverberry plants was found to have a beneficial effect on the growth performance of both silverberry and associated herbage (Bailey 1973).

Ability to Maintain/Increase

The competitive ability of silverberry is moderate. On the fescue grassland association of Alberta it was uncommon prior to intensive livestock grazing (Moss and Campbell 1947). One of the reasons for its lack of aggressiveness may be its relatively slow rate of cover spread (Freeman et al 1977).

Natural reproduction is by rhizomes and seed.

The species is fairly long lived. In one study, the oldest stems in the stands surveyed were 6 to 19 years (Whysong and Bailey 1975). However, no information was given on the clonal age which was likely much older.

Therefore, in areas where interspecific competition is not excessive, a silverberry stand may both maintain itself and increase in area or stem frequency. The species offers an advantage in reproducing vegetatively as well as by sexual means.

Propagation from Seed

Table 6 summarizes the information on methods of seed propagation. The literature was inconsistent on the need for germination pre-treatment and also pointed out the species' slow germination response and the existence of a germination inhibitor in its seed's endocarp.

TABLE 6

SUMMARY OF REVIEW ON GERMINATION PRETREATMENTS FOR SILVERBERRY (FROM: KING, 1980)

Reference	Germination Pretreatment(s)	% Germ Obtained	Location	Researcher's Comments
Anon., 1979	cold stratification at 41°F (5°C) for 60 to 90 days	80 to 90	Montana	
Babb, 1959	cold stratification at 41°F (5°C) for 75 days		Alaska	
Benson, per. com.	cold stratification at 38°F to 41°F (3.3°C to 5°C) for 30 to 90 days		Idaho	
Corns and Schraa, 1962	cold stratification at 5°C for 110 days	75 (after 20 days)	Alberta	in other testing endocarp removal gave 85 to 100% germ; endocarp contains a germination inhibiting substance
Cram, 1972	cold stratification at 6°C for 45 days	71	Saskatchewan	
DenHeyer, per. com.	cold stratification at 5°C for 2 months		Alberta	
Dick, 1979	cold stratification at 5°C for 60 days		British Columbia	
Heit, 1968b	none necessary		none given	because of seed coal texture, germination response is slow but acid treatment is not necessary; the species does not exhibit a dormant embryo (total germination was nearly the same with or without cold stratification)
Lohmiller, per. com.	cold stratification at 33°F to 38°F (0.6°C to 3.3°C) for 30 to 60 days		Montana	
Olson, 1974	cold stratification at 34°F to 50°F (1.1°C to 10°C) for 10 to 90 days		none given	
Shoemaker & Hargrave, 1936	cold stratification at 33°F to 40°F (0.6°C to 4.4°C) for one year		Alberta	germination response is slow due to hard seed
Simonson, 1976	none necessary (two lots)	42, 57	Alberta	

In an effort to resolve these questions, a factorial experiment was set up using cold stratification (in acid peat moss at 5°C for 0, 15, 30, 45, and 60 days) and cold running water leaching treatments (for 0, 24, 48 and 96 hours) as main effects. The seedlot used in the test was collected at latitude 49°30'N and longitude 114°20' and at an elevation of 1448 m asl.

The germination testing conditions used were: constant 20°C temperature, no light, germination paper subtrate, and a test duration of 21 days (with germination counts being done every seven days).

Water leaching significantly enhanced germination (Figure 3). Maximum cumulative germination of 50% was obtained with the 96 hour water leaching treatment. The effect of leaching became more exaggerated as germination time increased (Figure 4). In comparison cold stratification had little influence on germination. The positive effect of leaching parallels similar studies with *Astragalus lentiginosus* Dougl. (Zeimkiewicz and Cronin 1981) and suggests the presence of a water soluble germination inhibitor in the seed.

Species Requirements and Limitations

The autecological information for the species is summarized in Table 7. Silverberry is adapted to a wide range of site conditions. The major limitations on its use would include altitude, soil pH, and a potential disease problem.

SUMMARY

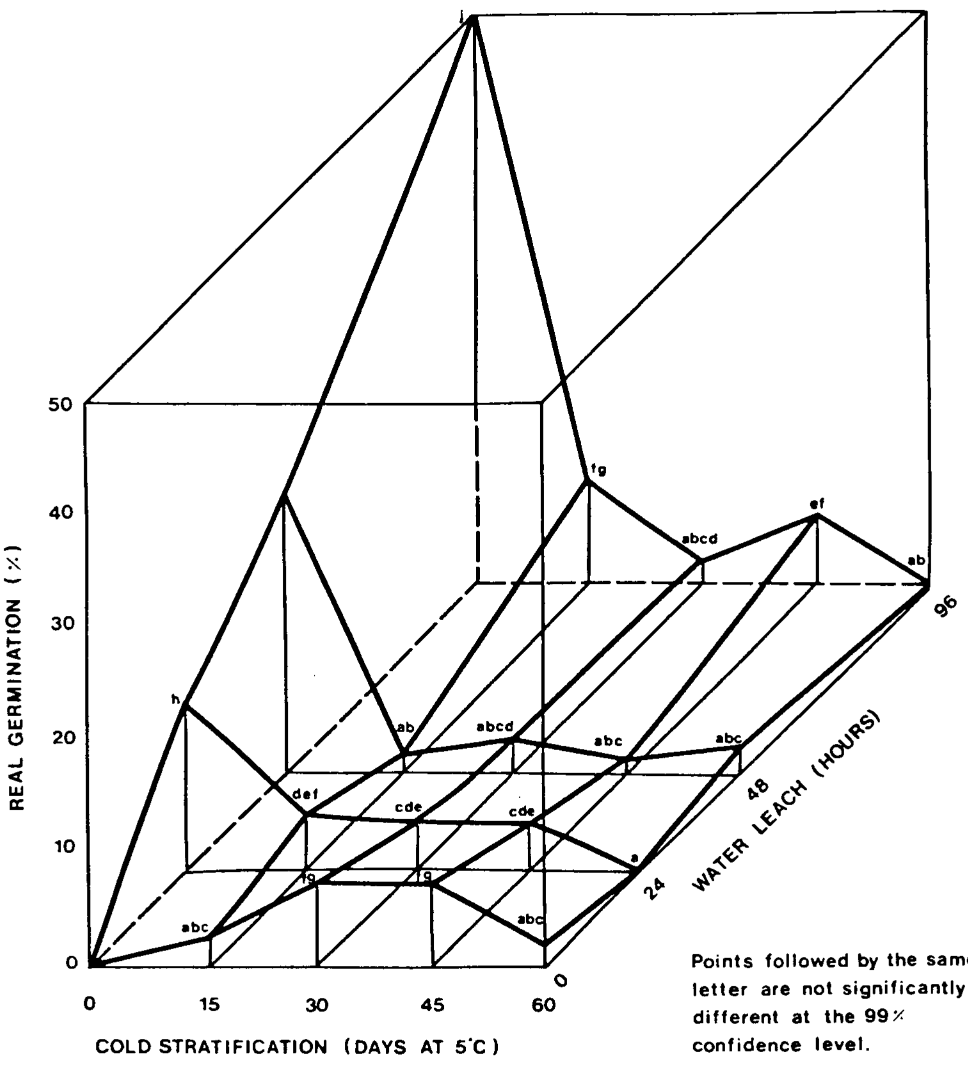
The Alberta Forest Service, Alberta Energy and Natural Resources has initiated a programme to evaluate and select native woody plants for reclamation in the Eastern Slopes of Alberta. The scope of the programme has been presented.

The evaluation process is a combination of currently available information and research. It is presently underway. Limber pine and silverberry are presented as examples of the process.

The seed of silverberry does not require cold stratification prior to germination. Rather, a cold running water leach would appear to be an optimum germination pre-treatment. Leaching for 96 hours gave the maximum real cumulative germination and most rapid germination rate (in the second and third weeks of the testing) in the species' seed testing.

FIGURE 3

GERMINATION OF SILVERBERRY SEED



Points followed by the same letter are not significantly different at the 99% confidence level.

FIGURE 4

SILVERBERRY GERMINATION DURING EACH SEED TESTING COUNT PERIOD

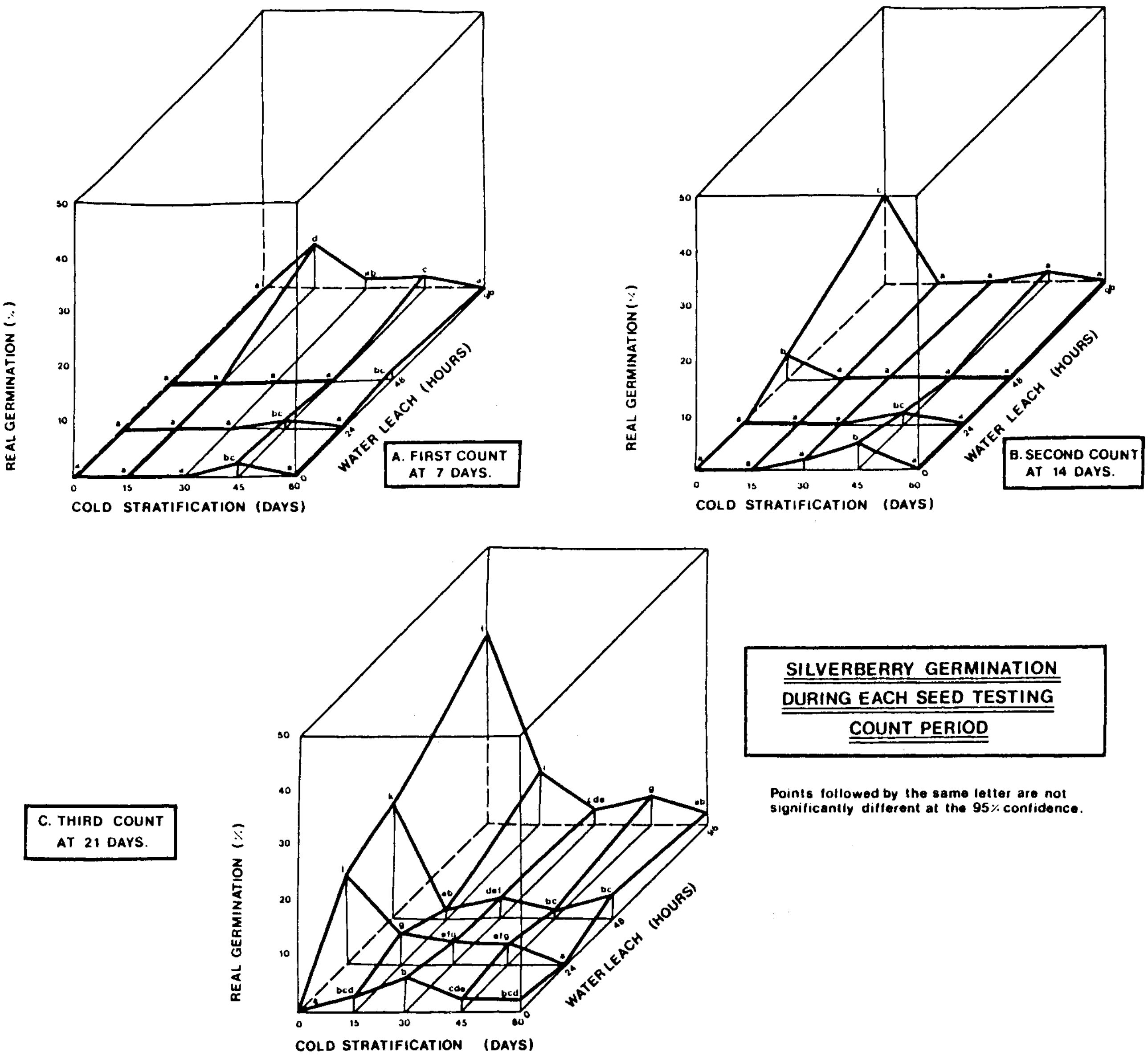


TABLE 7

SUMMARY OF AUTEOCOLOGICAL INFORMATION ON SILVERBERRY

Eastern Slope Distribution			Soils													
"Eco-region"	Alti-tudinal Range (m asl)	Lati-tudinal Range (*)	Parent Material	Soils Order	Depth (cm)	Texture	pH	Organic Matter/ Nutrients	Moisture	Drainage	Other	Drought Tolerance	Slope	Aspect	Insects	Diseases
fescue grass, aspen parkland	to 1550	49-54 N (through-out)	fine textured sediments, sand, porous gravel, shattered rock	cherno-zems, bruni-sols, regosols	shal-low (<15)	Sil, SL, S	6.0-7.5	low organic matter, low nitrogen	dry-moist	exces-sively drained to imper-fectly drained	toler-ant of high sodium levels	moderate-high	flat to very steep	all	1 on species	11 on species; that of major concern is _Puccinia coronata_ (crown rust); can cause serious damage in sec-ondary host Graminae

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7

INFLUENCE OF CULTIVATED GRASSES AND LEGUMES ON THE ESTABLISHMENT SUCCESS OF NATIVE GRASS MIXTURES AT TWO ABANDONED COAL MINES IN THE SUBALPINE REGION OF ALBERTA

by

H. Tomm and S.K. Takyi
Reforestation and Reclamation Branch
Alberta Forest Service
Department of Energy and Natural Resources
Edmonton, Alberta, Canada
T5K 2C9

INFLUENCE OF CULTIVATED GRASSES AND LEGUMES ON THE ESTABLISHMENT SUCCESS OF NATIVE GRASS MIXTURES AT TWO ABANDONED COAL MINES IN THE SUBALPINE REGION OF ALBERTA

ABSTRACT

Field experiments on land disturbances in the subalpine region of Alberta have indicated that, with a great majority of the native grass species tested, plant cover development necessary for rapid erosion control is generally slower than with the cultivated varieties. The objective of the present study is to define seed mixtures that will produce erosion-controlling cover and ultimately evolve into mature native plant communities.

Identical trials were established on both raw overburden and overburden topdressed with mineral soil on two abandoned subalpine coal mines to assess the influence of cultivated grasses and legumes on the establishment and performance of native grass mixtures. This report covers assessment results after the second growing season. Parameters discussed include percent plant cover, and a general assessment of species frequency.

INTRODUCTION

Reclamation of coal-mines disturbances in high elevation alpine or subalpine environments represent unique and often difficult challenges in land management. The high value of these areas for watershed, wildlife range and recreation serve to emphasize the need for successful reclamation. Unfortunately, there is a paucity of information with respect to rehabilitation of disturbed alpine or subalpine sites. Expertise developed for more temperate zones cannot always be applied to high elevation situations where a different and/or more critical set of environmental constraints are encountered. Of particular importance is the low heat budget under which plant species must complete their life cycle (Brown and Johnston 1979, Root 1976). Brown and Johnston (1979) suggest that three important and interrelated variables must be considered for successful high elevation rehabilitation: 1) overall climatic factors; 2) physiological adaptations of the plant; and 3) factors of the disturbed environment.

One phase of the Alberta Forest Service research program is directed at evaluating the physiological adaptations of native grasses for reclamation purposes. Emphasis has been placed on species adaptability trials in subalpine regions. Experience gained has indicated that despite the adaptations of high elevation native species, their cultivated counterparts are often more adept at producing an early erosion-controlling vegetative cover (Russell and Takyi 1979, Takyi and Russell 1980). Ziemkiewicz (1979) noted that this paradox is plausible because of the genetically-enhanced capacity of most agronomic species to produce shoot biomass. Conversely, adapted native species avoid the nutrient cycling "bottleneck" of slow decomposition of dead plant material in high elevation environments by maintaining relatively high proportions of root to shoot biomass. Thus, under favourable moisture and soil fertility conditions, cultivated species may initially be far more productive.

The designated end land use objective of reclamation often requires the establishment of a self-perpetuating native plant community. However, measures implemented to meet this objective will not necessarily ensure the simultaneous production of an erosion-controlling cover in the early stages of reclamation.

The present study was initiated in an attempt to define seed mixtures which will achieve both short- and long-term reclamation objectives.

Specific objectives of the study are as follows:

1. to evaluate and compare the main effects and interactions of five companion crop treatments and four native grass seed mixtures on the establishment of a vegetative cover on raw overburden and overburden topdressed with mineral soil at two subalpine locations, and

2. to evaluate and compare the performance of three cultivated grass-legume control mixtures and four native grass mixtures on the establishment of a vegetative cover on raw overburden and overburden topdressed with mineral soil at two subalpine locations.

Assessment results after the second growing season are presented. Because of the relatively short time span since the study was initiated, conclusions pertain only to the establishment of an early erosion-controlling ground cover.

DESCRIPTION OF STUDY AREAS

The experiments were established on two abandoned surface coal mines in the Eastern Slopes of the Rocky Mountains. The sites are near Cadomin (elev. 1,695 m) in west central Alberta, and at Adanac (elev. 1,895 m) in the southwest corner of the province. The study areas fall into in the subalpine forest region (SA.1) as defined by Rowe (1972). The same climatic classification, subarctic snow forest (Dfc) according to Koppens' systems, describes both areas (Longley 1970). Abandoned in the early 1950's, the mine sites are now characterized by spoil and overburden materials that are almost completely devoid of vegetation.

Further description of the Cadomin area can be found in Root (1976) and Russell and Takyi (1979). Tomm and Russell (1981) give a description of the Adanac mine site, as well as a summary of soil and overburden analyses for both sites.

MATERIALS AND METHODS

EXPERIMENTAL DESIGN AND TREATMENTS

Two separate but identical field trials were established at each study site; on raw overburden and overburden topdressed with mineral soil. The purpose of topdressing was to evaluate species establishment and performance on different seedbed types.

Each trial consists of three replicates employing a completely randomized design. Seed mixtures for the factorial native grass-companion treatments are given in Table 1. The cultivated grass-legume control mixtures are summarized in Table 2.

ESTABLISHMENT OF FIELD TRIALS

Field trials were established in the spring of 1979. For the topdressed trials, mineral soil was stripped from nearby undisturbed sites, hauled to the mine sites, and spread to an average depth of 20 cm.

Trials were fenced to minimize outside influences. All plots measure 2 m x 2 m (.0004 ha). Seedbed uniformity was achieved by hand raking each plot before and after broadcast seeding and fertilizing. Establishment fertilization was carried out at a rate of 80 kg N/ha, 60 kg

TABLE 1

TREATMENT DESIGNATIONS OF THE NATIVE GRASS SEED MIXTURES AND CULTIVATED COMPANION CROPS

Native Grass Mixtures[1]

1. Slender wheatgrass (Agropyron trachycaulum), alpine sheep fescue (Festuca saximontana), alpine bluegrass (Poa alpina) and interior bluegrass (P. interior).

2. Northern wheatgrass (Agropyron dasystachyum), bearded wheatgrass (A. subsecundum), slender wheatgrass and June grass (Koeleria cristata).

3. Northern wheatgrass, tufted hair grass (Deschampsia caespitosa), alpine bluegrass and spike trisetum (Trisetum spicatum).

4. Alpine sheep fescue, June grass, interior bluegrass and spike trisetum.

Cultivated Companion Crops[2]

A. Meadow foxtail (Alopecurus pratensis, Canada No. 1 seed).

B. Timothy (Phleum pratense cv. Climax, certified seed) and white clover (Trifolium repens, Canada No. 1 seed).

C. Creeping red fescue (Festuca rubra cv. Boreal, certified seed) and alsike clover (Trifolium hybridum cv. Aurora, certified seed).

D. Perennial ryegrass (Lolium perenne cv. Norlea, certified seed).

E. Control (no companion crop).

[1]Each mixture was seeded at a rate of 4,000 seeds/m^2. The number of seeds per species is approximately equal in each mixture.

[2]Each treatment was seeded at a rate of 5 kg/ha.

TABLE 2

TREATMENT DESIGNATIONS OF THE CULTIVATED GRASS-LEGUME SEED MIXTURES

Mixture[1]	Species[2]
a.	Creeping red fescue (Festuca rubra cv. Boreal, certified seed) (40%), white clover (Trifolium repens, Canada No. 1 seed) (20%), timothy (Phleum pratense cv. Climax, certified seed) (20%) and crested wheatgrass (Agropyron cristatum cv. Fairway, certified seed) (20%)
b.	Creeping red fescue (40%), white clover (12%), timothy (24%) and Canada bluegrass (Poa compressa, Canada No. 1 seed) (24%)
c.	Creeping red fescue (32%), timothy (20%), crested wheatgrass (32%) and alsike clover (Trifolium hybridum cv. Aurora, certified seed) (16%)

[1]Each mixture was seeded at a rate of 40 kg/ha.

[2]Percent figures in brackets following each species indicate proportion of seed mixture by weight.

P/ha, and 60 kg K/ha. The sources of fertilizer nutrients were 46-0-0, 10-30-10 and 0-0-60. Subsequent maintenance fertilization (spring, 1980) was applied at one-half the above rate using the same fertilizer forms.

ASSESSMENT OF FIELD TRIALS

Initial assessments (fall, 1980) included percent plant cover and species frequency. A general assessment of the latter index was obtained by ocular appraisal for the dominant species in each plot. Plant cover was measured in a 0.5 m by 0.5 m quadrat with grid of 100 subplots. Percent cover values were estimated on the basis of the perpendicular projection of all living above-ground plant parts. Plant cover percent was expressed as the mean of four quadrat readings per plot.

RESULTS AND DISCUSSION

NATIVE GRASS-COMPANION CROP TREATMENTS

Results summarized in Tables 3 and 4 show significant differences in percent plant cover among native grass seed mixtures in all trials except the topdressed overburden at Adanac (Table 4). Highest average percent plant cover in all trials was achieved by the native mixture composed primarily of wheatgrasses (northern wheatgrass, bearded wheatgrass, slender wheatgrass and June grass). Lowest percent cover resulted from the seed mixture lacking a wheatgrass representative: alpine sheep fescue, June grass, interior bluegrass and spike trisetum.

The robust performance of the wheatgrasses suggest that these species are suitable for initial revegetation. It remains to be determined if the wheatgrasses will continue to be a significant component of plant cover beyond the maintenance (fertilization) stage or be replaced by other species in the seed mixtures. For example, both the fescues and the bluegrasses approached the wheatgrasses in frequency of occurrence although contributing little to the present plant cover. Spike trisetum, June grass and tufted hair grass occurred much less frequently than the above species.

The companion crop treatments were not significant in any of the trials. Furthermore, the interactions between native grass mixtures and

TABLE 3

PERCENT PLANT COVER OF THE NATIVE GRASS-CULTIVATED COMPANION CROP TREATMENTS AT CADOMIN (MEANS OF THREE REPLICATIONS)

Native Grass Mixtures[1]	Companion Crop Treatments[1] A	B	C	D	E	Means[2] (Native Mixtures)
Topdressed Trial						
1	31.92	21.17	22.25	29.00	22.42	25.35b
2	38.08	31.92	29.50	25.42	22.42	29.47b
3	26.92	26.83	31.00	26.83	21.00	26.52b
4	17.67	17.92	13.42	12.58	10.00	14.32a
Means (Companion Crops)	28.65	24.46	24.04	23.46	18.96	
Raw Overburden Trial						
1	7.25	12.00	5.58	14.58	12.75	10.43b
2	15.58	20.00	24.75	27.58	21.17	21.82c
3	8.83	16.75	13.67	12.75	11.25	12.65b
4	5.17	3.58	5.50	3.58	1.08	3.78a
Means (Companion Crops)	9.21	13.08	12.38	14.62	11.56	

[1]Treatment designations:

Native Grass Mixtures

1. Slender wheatgrass, alpine sheep fescue, alpine bluegrass and interior bluegrass.
2. Northern wheatgrass, bearded wheatgrass, slender wheatgrass and June grass.
3. Northern wheatgrass, tufted hair grass, alpine bluegrass and spike trisetum.
4. Alpine sheep fescue, June grass, interior bluegrass and spike trisetum.

Cultivated Companion Crops

A. Meadow foxtail
B. "Climax" timothy and white clover
C. "Boreal" creeping red fescue and "Aurora" alsike clover
D. "Norlea" perennial ryegrass
E. Control

[2]For significant main effects, means followed by a common letter are not significantly different at the five (5) percent level according to Duncan's Multiple Range Test.

TABLE 4

PERCENT PLANT COVER OF THE NATIVE GRASS-CULTIVATED COMPANION CROP TREATMENTS AT ADANAC (MEANS OF THREE REPLICATIONS)

Native Grass Mixtures[1]	Companion Crop Treatments[1]					Means
	A	B	C	D	E	(Native Mixtures)
Topdressed Trial						
1	38.83	20.50	15.67	24.42	16.92	23.27
2	34.92	34.24	29.42	32.92	24.50	31.20
3	42.08	21.33	28.67	28.58	17.58	27.65
4	29.25	31.75	17.42	10.17	21.92	22.10
Means (Companion Crops)	36.27	26.96	22.79	24.02	20.23	
Raw Overburden Trial						
1	28.92	20.33	26.00	32.25	23.42	26.18a[2]
2	36.92	51.58	26.00	35.75	35.17	37.08b
3	39.17	38.42	34.33	24.17	20.08	31.23ab
4	29.75	32.50	33.58	28.92	22.17	29.38ab
Means (Companion Crops)	33.69	35.71	29.98	30.27	25.21	

[1]Treatment designations:

Native Grass Mixtures

1. Slender wheatgrass, alpine sheep fescue, alpine bluegrass and interior bluegrass.
2. Northern wheatgrass, bearded wheatgrass, slender wheatgrass and June grass.
3. Northern wheatgrass, tufted hair grass, alpine bluegrass and spike trisetum.
4. Alpine sheep fescue, June grass, interior bluegrass and spike trisetum.

Cultivated Companion Crops

A. Meadow foxtail
B. "Climax" timothy and white clover
C. "Boreal" creeping red fescue and "Aurora" alsike clover
D. "Norlea" perennial ryegrass
E. Control

[2]For significant main effects, means followed by a common letter are not significantly different at the five (5) percent level according to Duncan's Multiple Range Test.

companion crops were not significant, implying that these factors have independent effects on plant cover. Possible explanations are that 1) the effect of the companion crop treatments were similar on each native grass mixture or 2) the companion crops did not achieve sufficient cover to affect the establishment and growth of native species.

These preliminary results suggest that good plant cover production can be achieved through the use of native wheatgrasses. At the seeding rate tested in this study, the companion crop treatments were not essential for establishing an early erosion-controlling cover. The more successful of the companion crops in frequency of occurrence were meadow foxtail, timothy and creeping red fescue. These species may yet influence the performance of native grasses in subsequent seasons. Russell and Takyi (1979) found timothy to be one of the most promising species for erosion control at Cadomin. King (1980) and Mihajlovich and Russell (1980) noted that creeping red fescue was a successful colonizer of high elevation sites in southern Alberta. Brown and Johnston (1978) recommended meadow foxtail as one the few commercially available introduced species adaptable for high elevation reclamation.

Comparisons of average percent cover among all trials suggest contradictory results. Average percent cover for the trials at Cadomin were 23.9 (mineral soil) and 12.2 (raw overburden). Percent values for the respective trials at Adanac were 26.1 and 30.1. Despite this variation, the relationship of percent cover to species composition was relatively consistent, particularly for the native grass treatments.

NATIVE GRASS AND AGRONOMIC GRASS-LEGUME TREATMENTS

The preceding discussion intimated that the native wheatgrasses are suitable species for producing an early plant cover. Comparisons of the pure native grass mixtures with the cultivated grass-legume mixtures (Table 5) tend to support this claim.

Differences in plant cover attributable to seed mixture effects were not significant for the trials at Adanac. The summarized results (Table 5) suggest that the lower cover produced by the native seed mixture lacking a wheatgrass is responsible for the significant treatment effects for the trials at Cadomin. Native mixtures which included wheatgrasses generally compared favourably with the cultivated mixtures.

TABLE 5

PERCENT PLANT COVER OF THE CULTIVATED GRASS-LEGUME MIXTURES AND PURE NATIVE GRASS MIXTURES (MEANS OF THREE REPLICATIONS)

	Cadomin		Adanac	
Treatment[1]	Topdressed	Raw Overburden	Topdressed	Raw Overburden
a	38.33b[2]	23.50d[2]	22.33	35.50
b	35.08b	8.17ab	27.58	38.42
c	33.17b	13.25bc	29.17	38.83
1E	22.42ab	12.75b	16.92	23.42
2E	22.42ab	21.17cd	24.50	35.17
3E	21.00ab	11.25b	17.58	20.08
4E	10.00a	1.08a	21.92	22.17

[1]Treatment designations:

Native Grass Mixtures

1. Slender wheatgrass, alpine sheep fescue, alpine bluegrass and interior bluegrass.
2. Northern wheatgrass, bearded wheatgrass, slender wheatgrass and June grass.
3. Northern wheatgrass, tufted hair grass, alpine bluegrass and spike trisetum.
4. Alpine sheep fescue, June grass, interior bluegrass and spike trisetum.

Cultivated Companion Crops

E. Control (no companion crops).

Cultivated Grass-Legume Mixtures

a. "Boreal" creeping red fescue, white clover, "Climax" timothy and "Fairway" crested wheatgrass.
b. "Boreal" creeping red fescue, white clover, "Climax" timothy and Canada bluegrass.
c. "Boreal" creeping red fescue, "Climax" timothy, "Fairway" wheatgrass and "Aurora" alsike clover.

[2]For significant main effects, means followed by a common letter are not significantly different at the five (5) percent level according to Duncan's Multiple Range Test.

CONCLUSIONS

Results to date suggest that the native wheatgrasses are suitable species for initial revegetation of high elevation disturbances. The more successful of the native grass seed mixtures compared favourably with the cultivated grass-legume control mixtures.

The companion crops tested were not an essential ingredient for producing plant cover. These cultivated species did not significantly affect the establishment or growth of the native grasses up to the end of the second growing season after seeding.

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THE UTILIZATION OF NATIVE GRASS SPECIES FOR RECLAMATION OF DISTURBED LAND IN THE ALPINE AND SUBALPINE REGIONS OF ALBERTA

by

R.S. Sadasivaiah
and
J. Weijer
University of Alberta, Edmonton

THE UTILIZATION OF NATIVE GRASS SPECIES FOR RECLAMATION OF DISTURBED LAND IN THE ALPINE AND SUBALPINE REGIONS OF ALBERTA

INTRODUCTION

Asay, in a recent paper dealing with the revegetation of surface mining spoils in the western United States (1978), states that surface mining disturbed approximately four million acres and if all the coal in the United States now considered to be recoverable by strip mining were removed, 46 million acres would eventually be disturbed. I quote these estimates for the United States since they illustrate the immense task of revegetation facing this continent. Estimates reveal that nearly half the land area in Alberta, more than 100,000 square miles, is underlain by coal, of which some 400 billion tons is expected to be ultimately recoverable. While most of Alberta's coal reserves are too deep for surface mining, the sheer size of the resource and the pressures to develop it, portend a steady increase in the numbers of new mines, which signifies a steady increase in the amount of land to be disturbed and to be reclaimed so that "these lands afterwards become at least as productive, if not more so, than it was before", as stated in the Government of Alberta policy for coal development in the Province (June 1976). Some of our large mining spoils in the Province of Alberta are located in the subalpine and alpine regions and it can be expected that more will be created in the future, regardless of the legislative concern for environmentally sensitive areas.

The revegetation of subalpine and alpine regions is somewhat of a misnomer, in that the specification of subalpine and alpine regions would indicate that we deal with a problem which requires a revegetation technique sufficiently different from techniques in use for mountain and lower altitude areas. In principal however this is not the case; revegetation of alpine areas follows the same biological procedures and there is very little reason any more to deal with these disturbances under a special heading. As Soward and Leroy Balzer point out, "there is much potential for reclamation programs to suffer because of poor quality, insufficient quantities and limited varities of commercially available plant materials." Consequently, what has limited us in the reclamation of environmentally sensitive areas, such as subalpine and alpine regions, has been the availability of suitable biological material for reclamation purposes. Until 8 years ago very little breeding work had been done to develop improved varities specifically for mine land revegetation, yet it has been evident from the many failures in revegetation efforts, that no single species or variety will be adapted to the diverse environmental conditions encountered and it has become obvious that new genetic combinations with rather specific adaptive characteristics have to be incorporated into the material to be used in revegetation, be it grasses or other flowering elements. Cuany and co-workers at Colorado State University initiated a breeding and species evaluation program in 1974 to develop improved plant materials for reclamation of oil shale disturbed lands and revegetation of high altitude problem sites. Several native and introduced species were evaluated. Breeding efforts for the oil shale areas were centered around western wheatgrass *(Agropyron smithii)*, Indian rice grass *(Oryzopsis hymenoides)*, Lupines *(Lupinus spp.)* and Utah sweetvetch *(Hedysarum boreale)*. In the high altitude program emphasis was on smooth bromegrass *(Bromus inermis)* and to a lesser extent western wheatgrass and thickspike wheatgrass *(A. dasystachyum)*. Similarly, in 1974, the United States Department of Agriculture and the Forest Service initiated a grass breeding program to complement the existing cytogenetics and plant exploration program. In cooperation with Utah State University an attempt was made by Dr. Dewey to develop new grass varieties for arid range and for reclamation of lands disturbed by surface mining. This project emphasizes crested wheatgrass *(A. cristatum* and *A. desertorium)*, and Russian wildrye *(Elymus junceus)*. In addition, over 150 interspecific and intergeneric hybrids have been developed from crosses among these species. Several of these hybrids have excellent potential for use on rangeland and for revegetating surface mining spoils.

THE ALBERTA PROGRAM

Independently, similar efforts have been made in Alberta. In 1974 contracts with Alberta Environment, Alberta Fish and Wildlife, Alberta Forestry and Parks Canada, made it possible to start an evaluation program of native grasses originating on the eastern slopes of the Rocky Mountains for eventual use in reclamation efforts in the Province. Dr. Walker and co-workers assembled a large collection of native grasses comprising 37 species from alpine regions of the eastern slopes of the Rocky Mountains and transplanted these isolates to the Experimental Farm of the University of Alberta at Ellerslie at an elevation of 2,500 feet. In subsequent years seed was harvested from this collection and seedlings were raised in the growth-room facilities of the University. These seedlings were planted in small test plots throughout the Rocky Mountains at subalpine and alpine elevations at natural as well as disturbed sites and their performance was observed over several years. The evaluation of these different native grass species took into account several criteria. Survival rate, spreading ability, reproductive ability in terms of the production of mature seed under extreme environmental conditions, were necessarily the most important characteristics for eventual use in reclamation of subalpine and alpine regions. Walker in his initial study was able to recognize those native grass species which were best adapted to the very harsh climate of the alpine region of our mountainous area and therefore of potential importance for revegetation of alpine disturbed sites. The group of grasses based on their applicability can be divided into two groups: the Major Native Grasses to which *Agropyron dasystachyum, riparium, trachycaulum, latiglume, Deschampsia caespitosa, Poa alpinum* and *interior* belonq, and the Minor Native Grasses with *Festuca idahoensis, saximontana, Koeleria cristata, Phleum alpinum, Poa cusickii, Trisetum spicatum,* and *Agrostis scabra* as representatives.

GENETIC IMPROVEMENT

After establishment of our initial evaluation plots at Ellerslie Experimental Farm it became evident that all species assembled, represented a broad genetic variation but that some were plagued with cytological meiotic irregularities and sterility problems, which without genetic improvement, would render them unsuitable for commercial production. Selection in the *Agropyron* species was already started in 1976 and after the appointment of Dr. Sadasivaiah, genetic improvement of all species was undertaken. The main criteria used in this selection were:

1. winter hardiness
2. plant vigor and growth habit
3. tillering date
4. heading date
5. disease and insect resistance
6. uniform growth and maturity
7. seed shattering habit
8. seed yield

Of these characteristics winter hardiness, the ability to produce tillers as a means of vegetative reproduction, the ability to flower early in the vegetative cycle of the grass and to produce seed within the growing season and the overall seed yield are the most important. The characteristic of seed shattering, that is to say the ability to shed seed over a prolonged period of time, is of ecological importance, thereby minimizing the effect of adverse weather and other environmental conditions upon the natural process of seed dispersion and seedling establishment. Of the native grass species chosen for genetic improvement, all except *Agrostis scabra* have been grown for at least three selection cycles and as a result of this, sterility problems, as we encountered initially in some of the grasses, have been overcome. Remarkably uniform lines have been established for those species which are self pollinators or apomictic. For a cross-polinating species such as *A. dasystachyum,* isolates from different collection locales were planted together in a breeding field and were allowed to intercross freely. Seed of individual but promising plants was collected and seeded into selection lines. Further selection among these lines have produced high yielding progenies, which although cross-polinating, transfer the ability of high seed yield to their offspring. These polycross selection lines have the advantage of a built-in genetic variation, so highly desirable for the industrial use of this plant material. For instance, genetic variation in heading dates makes it possible to prolong the time of seed dispersal as compared to a highly uniform line which results from selection of a self-pollinating native grass species. It is for this reason that selected lines from self-pollinating species, showing a high degree of uniformity for all the characteristics used in the selection, are in themselves too restricted for reclamation purposes under extreme environmental conditions. In the development of commercial varieties attention has to be paid to the selection of lines differing in heading dates or, in other words, early and later maturing varities have to be established. For reclamation purposes the seed of these lines differing in maturing dates (but similar with regard to drought resistance, shattering habit, winter hardiness and seed yield), are mixed. Such a mixture would allow for a relatively long seed disposal time which especially under severe environmental conditions (as prevails in subalpine and alpine regions) may benefit the natural reproduction of the species. Other grasses such as the *Poas* and *Deschampsia* are apomictic to a high degree. They tend to reproduce almost true to type and selection in these grasses is relatively simple since a superior isolate will transmit its characteristic to its progeny with little or no segregation. Lines developed in these grasses show a remarkable homozygosity and therefore the actual selection procedure is greatly reduced timewise. So far this selection project with different native species (which is the largest on the continent) has produced several selections which have been registered for licensing. This year selection lines of *A. dasystachyum, A. trachycaulum* and *A. subsecundum* have been submitted to Canada Department of Agriculture and it is envisaged that selected lines of *Poa interior* and *Poa alpina* will become available for licensing some time late 1982 with the rest *(Deschampsia caespitosa, Festuca saximontana, Koeleria cristata* and *Trisetum spicatum)* in subsequent years. A start has been made with the seed increase of selected lines to allow commercial development of these lines within the near future.

EVALUATION OF NATIVE GRASSES

In order to monitor the performance of native grasses, as compared to commercial agronomics, and to determine a method of revegetation for disturbed areas at high elevation, a large testing area was established in 1977 at the Ptarmigan site of Whitehorn Mountain in the Lake Louise ski area beside the Trans Canada Highway, 40 miles west of Banff. The Ptarmigan site has an elevation of 2,290 m (7,500') and is located just above the treeline. The site faces east and has a slope of varying degrees ranging from 30 to 10. This site was disturbed by bulldozing equipment during the construction of the ski run. The soil structure is a coarse glacial till with a large amount of rocky material of all sizes. The soil analysis characterizes this soil as high in potassium (148 lb./acre). Nitrogen is present at 3 lb./acre, phosphorus at 11 lb./acre and sulphur at 2.7 ppm. The number of frost-free days during the summer season varies between 45 to 58. The following parameters were incorporated into the experiment:

1. Nineteen species of native grasses were planted to compare against each other and against four commercially available varieties in nine replications.

2. Two rates of inorganic fertilizer 26-13-0 at 100 kg/ha and 25 kg/ha were applied to six of the replications. Three replications were left untreated for a control.

3. A light covering of peat moss was applied to the seeded species of grass to determine if seedling establishment can be improved by this treatment. This test was replicated three times.

4. The effect of different gradients of slope was monitored. Three replications were at a slope of 30°, three were at 20° and three were at 10°.

The testplot was evaluated in 1980. The plots were examined for vegetative growth, ground cover and ability of species to reproduce. Those species which showed good ground cover and also flowered in most plots, were considered valuable in reclamation programs of high elevations.

The various species used in this study showed significant differences in their performance. In general, the native species performed better than the agronomic species, which due to their late flowering in the alpine season are unable to reproduce. Some of the native species that were found to be superior in their ability to survive and reproduce under alpine conditions were *Agropyron latiglume, Agropyron dasystachyum, Agropyron trachycaulum, Agrostis scabra, Deschampsia caespitosa, Festuca saximontana, Festuca rubra, Phleum alpinum, Poa alpina, Poa interior,* and *Trisetum spicatum.*

The application of a peat mulch did not have a significant influence on seedling establishment; however one has to take into account that a sloped area was used with an angle variation of 30° to 10°. Light material such as a peat mulch may have slid off the site applied or blown away before it could become effective. Notwithstanding this, there is some evidence that some grasses react adversely to mulching. From the percentage seedling establishment it can be deduced that mulching at the time of seeding is not required.

Similarly the application of fertilizer at the time of seeding had no effect. These results correlate with those obtained at Ellerslie Farm of the University of Alberta where no significant differences were observed between fertilized and unfertilized test rows. For genetic reasons these results can be predicted. The native grasses collected by us originated from areas where environmental conditions including soil conditions were extremely poor and hence these native grasses acquired in time a hereditary low requirement for nutrients as they did for tolerance toward the economic niche in which they developed. Native grasses at alpine elevations are slow growing but persistent. They flower very early during the alpine summer and are able to produce mature seed. It is our view that very little can be gained by fertilization at these altitudes and indeed, there are more drawbacks to this than benefits. The alpine summer is extremely short and the combination of fertilizer, drought and late rains may extend the growing season of the native grasses beyond the time that these grasses have to become dormant. Although long term fertilization of native grasses may have an aesthetic influence by increasing biomass, there is no evidence that such a fertilization program will greatly influence the tillering ability of the native grasses and no evidence that it has an influence on seedling establishment. As with many things in life, time is what is needed in order to come to good results. In the reclamation of subalpine and alpine spoils time is a most important factor.

Due to their low nutrient requirement as a genetic adaptation to the alpine environment, native grasses are slow growing at alpine sites, and hence it is unreasonable to expect instant coverage. Overseeding, a practice not uncommon to reclamation, is no solution to improve initial coverage. Our experiences with native grasses points to the fact that it will take approximately three years before these grasses reach maturity and become reproductive. The tolerance of native grasses toward the substrate is most remarkable. Our test plots at 6,500' at Sunshine Valley all located on a shale slag with a minimum of fine soil material indicates that although slow growing, native grasses are able to establish themselves at this high altitude regardless of the poor soil condition. Sowards and co-workers in their publication on seed procurement of native species of plants for arid land reclamation, state that the quality of plant materials used in reseeding disturbed lands probably has as much impact on the success or failure of a revegetation project as any factor subject to the control by the reclamation specialist. This issue is particularly timely with present emphasis on coal development. It would be in Canada's interest to follow the United States in this respect who now require that mine operators use native plant species to reclaim lands to equal or better production and moreover to enforce adequately the regulation that the operator proves his ability to successfully reclaim the land before a permit to mine will be issued by the regulatory authority.

DEVELOPMENT OF VEGETATION AND SOIL ON HIGH ELEVATION RECLAIMED LANDS IN SOUTHEASTERN BRITISH COLUMBIA

by

J.W. Fyles, I.H. Milne and M.A.M. Bell
University of Victoria

DEVELOPMENT OF VEGETATION AND SOIL ON HIGH ELEVATION RECLAIMED LANDS IN SOUTHEASTERN BRITISH COLUMBIA

ABSTRACT

Seeded grasses and legumes become established on waste dumps in the first growing season following seeding and significant growth takes place in the second year. The vegetation appears to be dependent on fertilization for approximately five years. Older reclaimed areas support shoot and root growth, soil CO_2 evolution, and available soil organic matter at levels similar to those at undisturbed grasslands. Native soils contain higher levels of humus although reclaimed soils may contain resistant organic matter originally derived from coal or carbonaceous shale. Carbon and nitrogen compounds, indiginous in the waste rock, may play an important role in the development of reclaimed areas.

INTRODUCTION

On Thursday we will be taking a bus tour to the high elevation reclaimed areas on the property of B.C. Coal Ltd. (formerly Kaiser Resources Ltd.) near the town of Sparwood, about one and one-half hour's drive east of Cranbrook. This paper will act as an introduction to that tour, describing some aspects of the development of vegetation on coal mine waste and changes which occur in the spoil materials within the first ten years after their deposition.

THE SETTING

The reclaimed areas under consideration are a byproduct of the open pit coal mining. In recent years, the mine has produced up to seven million tons of metallurgical coal and has generated approximately 70 million tons of waste rock annually. The mine is a truck and shovel operation in which the overburden rock is blasted and then removed by trucks to be deposited in extensive waste dumps.

In preparation for reclamation the dumps are resloped using bulldozers to an angle of approximately 26°. A seed bed is prepared on the dump surface using a heavy pipestem harrow to break surface compaction and to provide microsites to aid in seedling establishment. The seed mix, which includes a number of grass and legume species, is broadcast by helicopter either in the early spring or the late fall. The seeding is followed by a fertilizer application (13-16-10) at 200 kg/ha. After seeding and fertilization, the dumps are reharrowed to incorporate seed and fertilizer in the soil.

The reclaimed areas are refertilized each year at a rate of 200 kg/ha of 13-16-10 fertilizer.

Over the past five years, research has primarily been directed toward the evaluation of the success of fertilizer maintenance, either from the point of view of increasing fertilizer efficiency through the use of different fertilizers, application rates and times or from a long term point of view, assessing the effect of management on the development of reclaimed soils and vegetation. One of the major and continuing problems is to determine the period of time that maintenance will be required before a reclaimed area could be considered self-sufficient.

SAMPLING AREAS

Most of the data presented in this paper has been obtained from a series of sampling plots ranging in age from unvegetated spoil (zero years) to six years old. All of the plots are located in level areas with a south westerly exposure at an elevation of approximately 2000 m. In choosing sampling areas, an attempt was made to ensure homogeneity of vegetation and spoil type between plots.

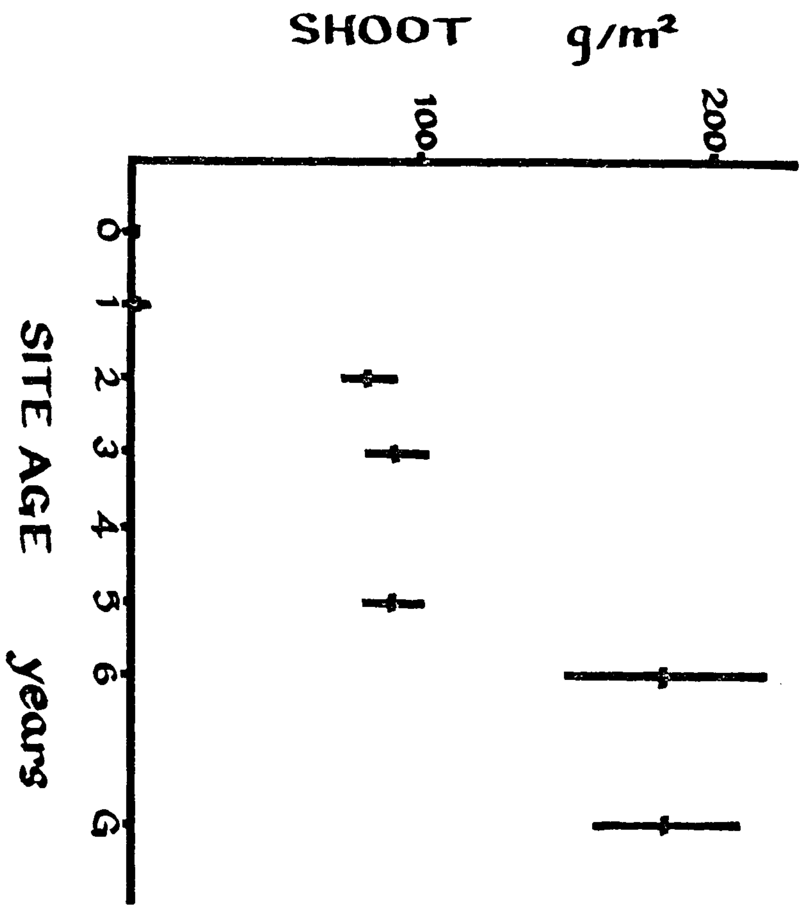
Since the oldest reclaimed site was only six years in age, an undisturbed native grassland adjacent to the reclaimed areas was included in the sampling as an example of a well established community which had developed under conditions similar to those of the reclaimed areas. Although the original parent material of the grassland soil was probably similar to that of the reclaimed areas, the site was located on a steep, southeasterly facing slope. In addition, the composition of the vegetation differed significantly from the reclaimed areas as it consisted entirely of native grasses, forbs and shrubs rather than agricultural species.

RESULTS AND DISCUSSION

The data shown in Figure 1 demonstrates that the establishment of vegetation is accomplished in the first growing season following seeding but actual shoot growth is very low until the second year. In the few

FIGURE 1

SHOOT GROWTH ON RECLAIMED AREAS OF DIFFERENT AGES AND THE NATIVE GRASSLAND (G). DATA POINTS IN THIS AND FOLLOWING FIGURES REPRESENT MEANS WITH 95% CONFIDENCE INTERVALS.



years following, it appears that growth remains relatively constant. The level attained is roughly that which would be expected with an input of 2 g/m^2 to 3 g/m^2 of nitrogen. Since this is the rate of annual fertilizer application we feel that this period of uniform growth is probably the result of the dependence of the vegetation on fertilizer nitrogen during the early years.

The shoot growth on the six year site is considerably higher than the other reclaimed areas despite the fact that it was not fertilized in the year of sampling. This suggests that the processes of nutrient storage and cycling are taking place on this site to a degree that will allow substantial growth of vegetation without the fertilizer nutrient supply.

The similarity in the levels of shoot growth measured on the six year site and the natural grassland may indicate that, at least in the year of sampling, growth in these areas was limited more by climatic conditions than by nutrient supply.

We found a number of close similarities between the undisturbed grassland and the six year site, some of which are shown in Figure 2. In addition to shoot growth discussed above, there are comparable levels of root biomass in the surface 10 cm of these sites. The slightly higher root density measured in the reclaimed site has been found in other reclaimed areas as well and may be caused by the stimulation of surface root growth by annual top dressing with fertilizer.

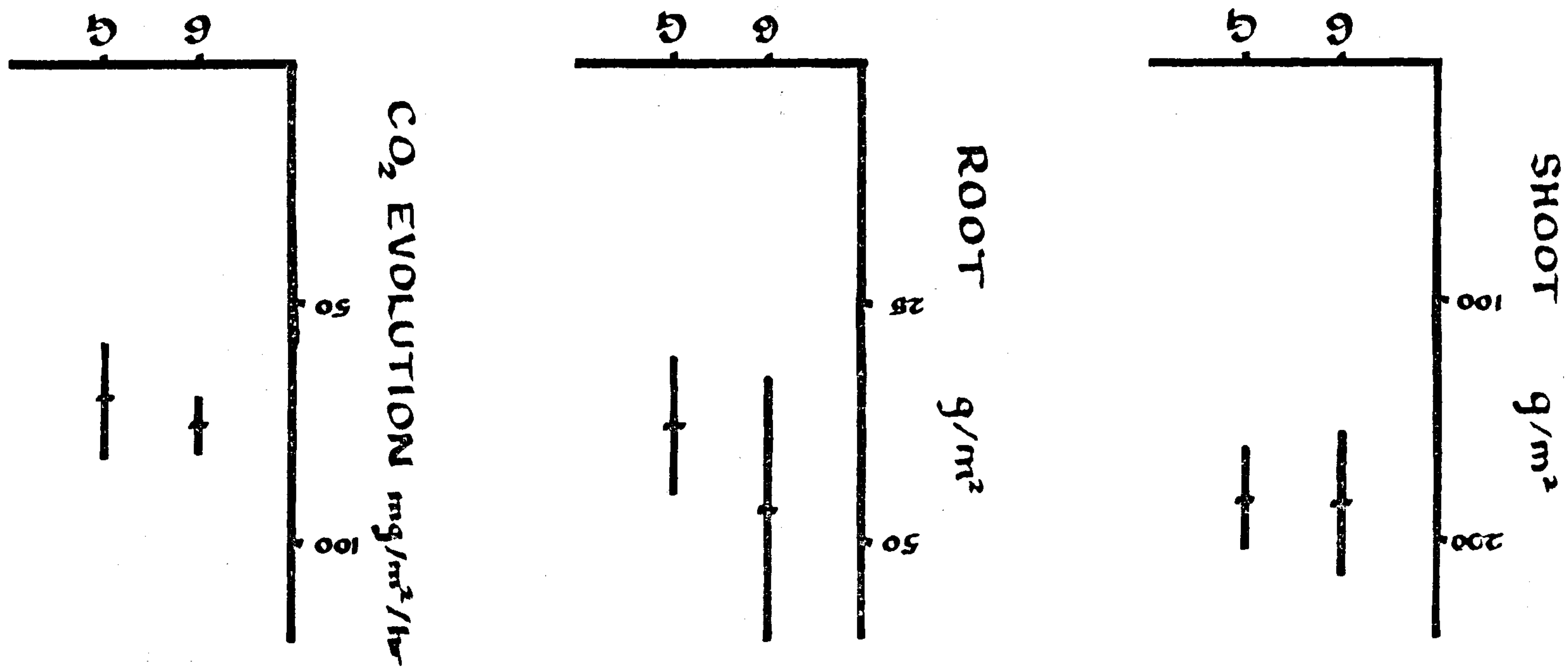
The evolution of CO_2 from the soil surface in the field can be broadly interpreted as an index of the overall metabolism of below ground organisms including micro-flora and fauna, and larger organisms such as arthropods and worms as well as plant roots (Macfadyen 1971). We measured very similar levels of CO_2 evolution from the soils of the oldest reclaimed site and the undisturbed grassland (Figure 2).

In addition to similarities in biological parameters between the reclaimed and undisturbed areas we found the concentrations of several soil nutrients, including available phosphorus, potassium and other exchangeable cations, to be comparable in the two soils.

The data presented above suggests that management practices have been successful in developing a reclaimed soil/vegetation system which, in many respects, resembles an undisturbed condition. Differences,

FIGURE 2

SHOOT AND ROOT GROWTH AND CO_2 EVOLUTION OF SOIL IN THE FIELD IN THE SIX YEAR OLD RECLAIMED SITE AND THE NATIVE GRASSLAND (G)



however, were found in the soil organic matter and nitrogen contents of the two soils and these require further considerations.

Initially, we expected that both soil organic matter and nitrogen would increase as reclaimed areas developed, since it has been a rule of thumb that fresh mine waste is low in both of these soil constituents. We found, however, that the reclaimed soils contained relatively high levels of total nitrogen which did not increase with time (Figure 3). In addition, fertilizer inputs could account for only 2% to 3% of the total nitrogen measured in the oldest reclaimed site. Further analysis indicated that the native rock which made up the mine waste contained up to 0.18% nitrogen.

The level of total nitrogen measured in the undisturbed grassland soil is far greater than any of the reclaimed sites. We attribute this high level to a natural accumulation over time rather than a base level determined by the composition of the local rock as suggested for the reclaimed areas.

Three different aspects of carbon in the soil were examined. The Walkley Black wet oxidation method (Allison 1965) measures the quantity of carbon that is readily oxidized, and assumed to participate in soil functions but not necessarily readily available for microbial use. A respiration study (Waksman and Starkley 1924) was used to estimate how much soil carbon was available for utilization by micro-organisms and a dry combustion method measured the total carbon which includes those forms which are met readily oxidizable and are assumed to be inert.

The levels of readily oxidizable carbon in the soils studied followed a pattern similar to that of total nitrogen. These data (Figure 4) indicate that even unvegetated spoil contains a relatively large proportion of readily oxidizable carbon. This carbon is probably contained in coal or carbonaceous shale and may be associated with the indigenous nitrogen discussed above. The native grassland soil contains a much higher level of Walkley Black carbon than the reclaimed sites, again, probably a result of natural accumulation. An incubation method was used to provide an index of the amount of available organic matter in each soil. In this method, the CO_2 evolved by soil samples incubated in sealed containers were measured, and assumed to be proportional to the amount of carbon in the soil easily utilized by micro-organisms. This type of organic matter consists mainly of compounds derived from living, or recently living plant or animal material.

FIGURE 3

TOTAL SOIL NITROGEN IN RECLAIMED AREAS OF DIFFERENT AGES AND THE NATIVE GRASSLAND (G)

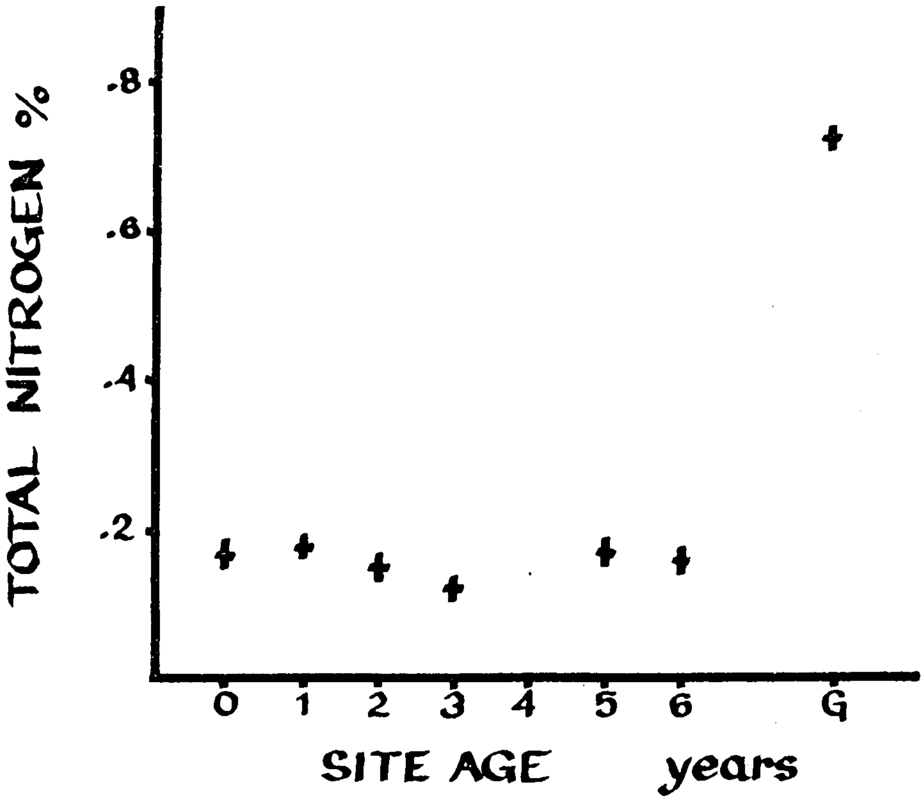
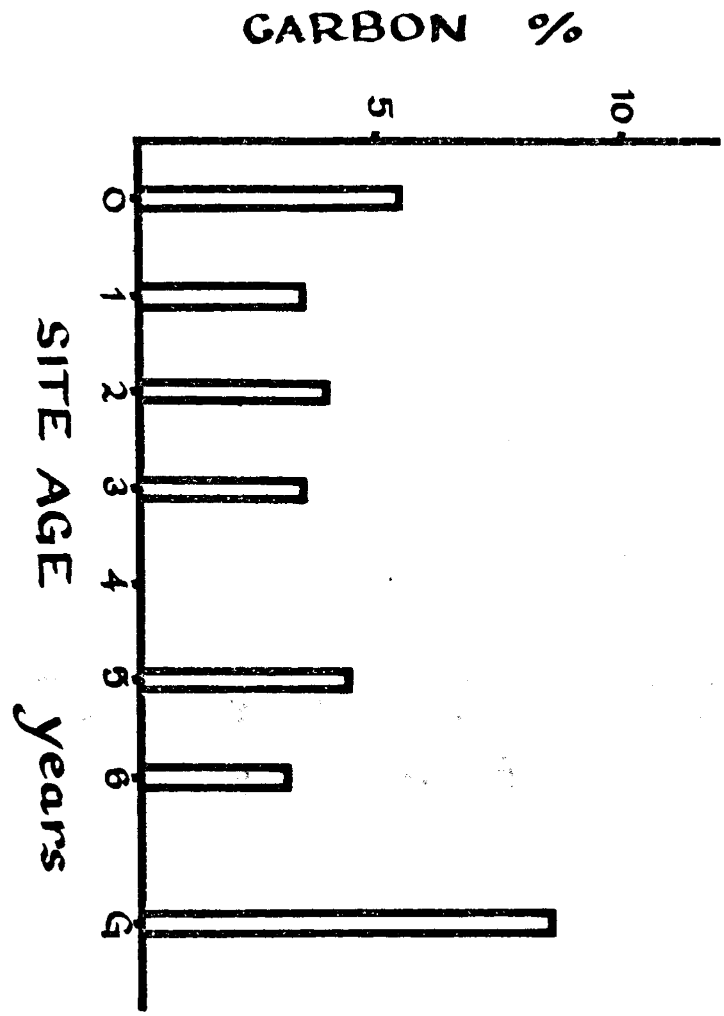


FIGURE 4

READILY OXIDIZABLE SOIL CARBON IN RECLAIMED AREAS OF DIFFERENT AGES AND THE NATIVE GRASSLAND



We found that CO_2 evolution increased significantly with age in reclaimed soils (Figure 5) and that the soil of the six year reclaimed site evolved CO_2 at a rate similar to that of the undisturbed grassland soil. Considering the high level of readily oxidizable organic matter in the grassland soil discussed above (Figure 4), and the comparatively low level of available carbon implied by the CO_2 evolution data, it is apparent that this soil must contain a large proportion of carbon which is readily oxidized but not easily utilized by micro-organisms.

The soil substances which are generally referred to as humus are the end or byproducts of the decomposition of organic matter, and are resistant to further microbial degradation. Although only 2% to 3% turnover of soil humus can be expected annually (Janssen 1972) these substances play an important role in nutrient storage and exchange and strongly affect soil texture, structure, and moisture holding capacity (Brady 1974). Analysis of soil samples for humic and fulvic acids, major constituents of humus, confirmed that the soil of the native grassland contained a much higher proportion of humus than the reclaimed soils.

In simplified terms, the organic matter of the grassland soil can be described as a small pool of readily available carbon compounds in association with a large pool of resistant humic substances (Figure 6). A reclaimed soil, in comparison wauld have a similar sized available pool with a much smaller pool of resistant material.

The pool of resistant organic matter in the reclaimed soil may have been derived from plant residues and more available substances but may also have originated as indigenous carbon in coal or carbonaceous shale. In order to study this problem further we collected samples of unvegetated carbonaceous spoil which had been exposed to weathering on the dump surface for varying periods of time ranging up to ten years. The samples were analysed for total carbon using dry combustion and for readily oxidizable carbon as a previous analyses. We found that in our youngest samples less than 35% of the total carbon was in a readily oxidizable form while almost 80% was easily oxidized in our most weathered spoil (Figure 7). The CO_2 evolution of similar samples, innoculated with soil suspension, suggested that this increase in ease of oxidation was not accompanied by an increase in available organic matter. These data suggest that indigenous carbon is altered by weathering to form less inert compounds which, while not easily utilized by micro-organisms, may be more likely to participate in soil

FIGURE 5

CO_2 EVOLUTION OF SOILS OF RECLAIMED AREAS OF DIFFERENT AGES AND NATIVE GRASSLAND (G) MEASURED UNDER LABORATORY CONDITIONS

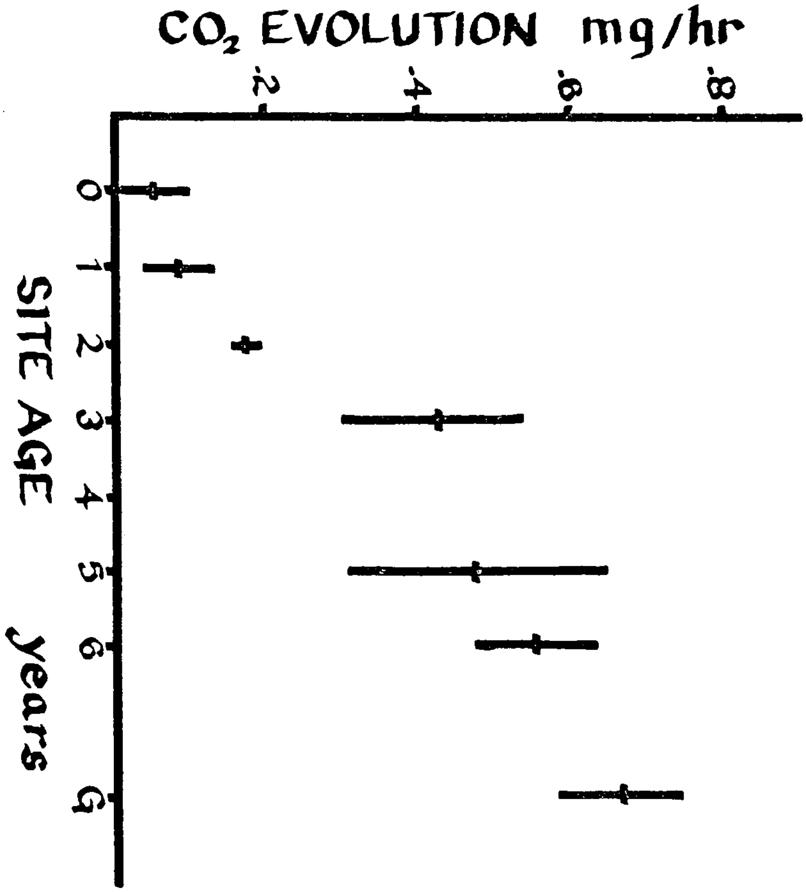


FIGURE 6

DIAGRAMATIC REPRESENTATION OF THE ORGANIC MATTER (O.M.)
OF RECLAIMED AND UNDISTURBED SOILS

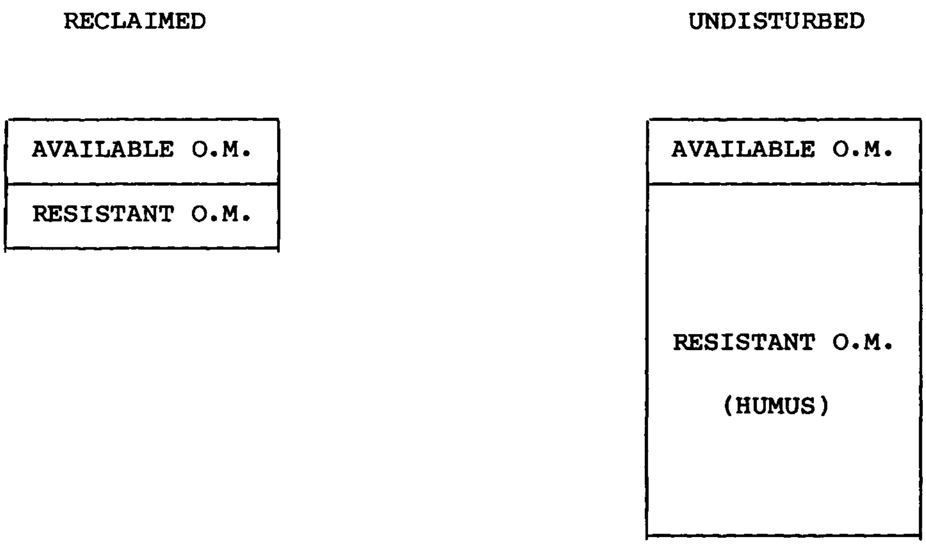
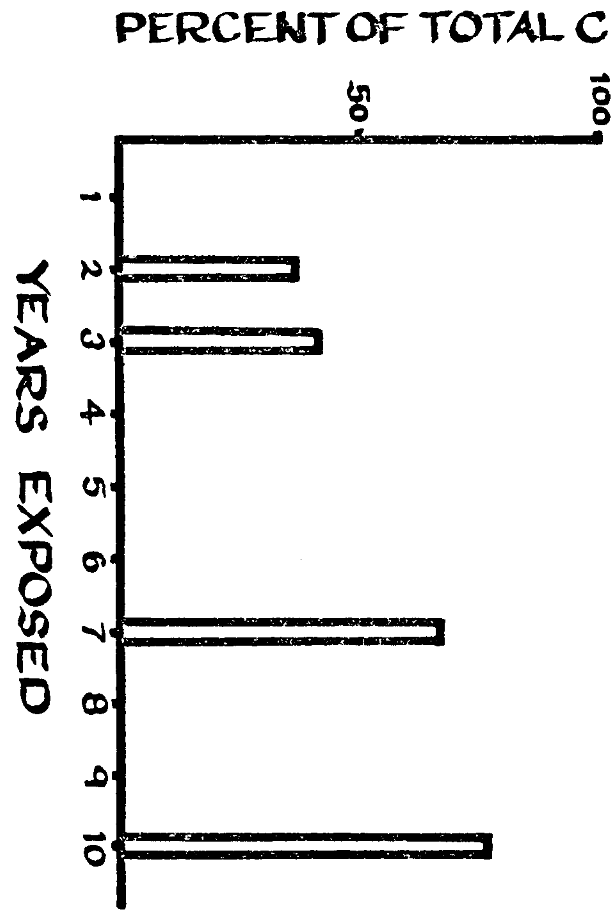


FIGURE 7

THE PERCENT OF THE TOTAL CARBON WHICH IS READILY OXIDIZED IN SPOILS EXPOSED TO WEATHERING FOR VARYING PERIODS OF TIME



functions. Although the data are preliminary it seems clear that any investigation of organic matter in soils developing on carbonaceous spoil must consider the influence of indigenous carbon sources, as well as conventional decomposition pathways.

CONCLUSION

Our research has shown that the ecological development of reclaimed mine waste is rapid under annual fertilizer maintenance. Although the reclaimed areas appear to be dependent on fertilization for several years, they rapidly reach a condition which is similar in many respects to undisturbed grassland soils. The major difference between native and old reclaimed soils appears to be in the amount of humus accumulation. Reclaimed soils seem to have low levels of humic materials and, although they may contain resistant organic matter originally derived from indigenous carbon compounds, the function of these substances in soil processes is not clearly understood. Carbon and nitrogen compounds contained in the spoil materials represent a large reservoir of potentially available nutrients and organic matter which could have a significant influence on the development of a truly nutrient self-sufficient vegetation/soil system on reclaimed mine waste. Further research is required to provide a better understanding of the role of soil organic matter in the nutrient self-sufficiency of reclaimed areas and of the effect of weathering on the availability of indigeneous carbon and nitrogen.

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ESTABLISHMENT OF WOODED LANDSCAPES FROM SEED ON DISTURBED LAND; THE EFFECTS OF ASPECT AND MULCHING ON SEEDLING RECRUITMENT AND GROWTH

by

A.G.R. Luke
University of Cambridge, England

ESTABLISHMENT OF WOODED LANDSCAPES FROM SEED ON DISTURBED LAND; THE EFFECTS OF ASPECT AND MULCHING ON SEEDLING RECRUITMENT AND GROWTH

ABSTRACT

Slopes of varying aspect commonly occur as a result of regrading mine spoil heaps and in earthworks associated with highway developments. Aspect and slope affect soil temperature and moisture availability, which control seed germination and seedling emergence. Poor seedling emergence, survival and growth has been observed on different aspects. Information from previous studies on these affects is summarized and compared with recent studies on broadleaved species. Experimental work on mine spoil and highway developments investigated the effects of aspect on the seedling recruitment and growth of Common alder *(Alnus glutinosa)*, Sycamore *(Acer pseudoplatanus)* and Pedunculate oak *(Quercus robur)*. Species responded differentially to the effects of aspect. The experiments indicated that soil moisture and temperature could be modified by mulching, which increased seedling emergence. The effects of aspect on seedling recruitment can be ameliorated by the application of a mulch.

ASSESSMENT OF THE SOIL RESOURCE IN THE RECLAMATION OF DISTURBED MOUNTAINOUS AREAS

by

Dr. Michael J. Rowell
Norwest Soil Research Inc.
Langley, British Columbia

9

ASSESSMENT OF THE SOIL RESOURCE IN THE RECLAMATION OF DISTURBED MOUNTAINOUS AREAS

INTRODUCTION

When choosing soil assessment methods for land reclamation we must go beyond traditional soil testing concepts. Soil characteristics as they are now and changes in soil properties with time concern us equally.

To clarify this, it is useful to draw a distinction between soil testing and soil analysis.

Soil testing methods have been developed primarily for farmers with the purpose of studying the current status of the soil, particularly its fertility, and to recommend the addition of nutrients and amendments to maximize crop production. Interpretation of data is often highly dependent upon research experience which is used to calibrate the testing methods for particular crops and soils within a limited geographical area. Fertility testing methods are generally used for annual crops. Tests are made in the fall or early spring from bare soil and are hoped to indicate nutrient levels prior to seeding. Application of these methods to perennial agricultural crops or to forest production has met with more limited success.

True soil analysis is a more precise science and requires a more comprehensive understanding of the soil both vertically and horizontally. The objectives are more diverse and take into account longer term aspects of soil quality and the relationship of the soil to the landscape.

In land reclamation problems, we study a variety of soil materials ranging from surface soils, rock fragments, mineral overburdens, tailings to subsoils. The legislation we are constrained by contains phrases such as "self-sustaining vegetation" and "soil productivity to be as good as or better than prior to disturbance." The correct choice of analytical techniques is most critical to meet our various objectives. Little has been offered to date to explain what constitutes soil quality under particular defined conditions. For instance, it is generally assumed that cultivation of prairie soils has resulted in a decline in their quality (Alberta Soils Workshop, 1980). This obviously has something to do with deterioration in organic matter contents, soil erosion, salinization and so forth, but we are unable to agree on critical levels or management solutions. How much organic matter is enough? How do we measure the quality of organic matter?

In this paper, I have not attempted to comprehensively discuss soil assessment in terms of type of analyses required or the preferred methodology. Neither have I discussed the organization of the reclamation element as it fits into the commercial development of a new resource. I have tried to look in a general way at the type of soil characteristics which are important, point out the usefulness of the information obtained, and in some instances discuss the potential problems in analysis and interpretation. Since the theme of these meetings is high altitude reclamation, I have also tried to place most emphasis on assessments of soil in mountainous areas.

MOUNTAINOUS AND HIGH ALTITUDE TERRAIN

Most problems encountered in the reclamation of disturbed areas at high altitude or in mountainous terrain are not specific to just those situations. However, the effects of steep slopes and low temperatures result in more severe problems than are normally encountered at lower elevations. Therefore, reclamation programs have to be conceptually well thought out and executed at a higher level of initial effort and subsequent management than elsewhere.

Management of the physical state of disturbed soils in mountainous areas is most critical due to the potentially erodible nature of the land surface. Steep terrain at high altitude is subject to extreme climatic conditions of high winds, intense storms, avalanches and flooding in exposed areas. Stabilization of slopes with vegetation is difficult to achieve due to naturally infertile and potentially droughty soils, and to meagre plant growth during the short cool growing seasons.

Mountain soils are typically weakly developed, of variable depth and generally contain thin accumulations of organic matter. Lack of organic matter and low soil temperatures result in poor recycling of nutrients, particularly nitrogen. Low moisture holding and water interception characteristics often result in a poor moisture status within the rooting zone during much of the growing season.

Topsoil salvage would in practical terms involve removal of the A, B and probably part of the C horizon.

Plants growing in mountainous areas at high altitude are predominantly perennial (Eamon 1974). The annual pioneer types common in disturbed low altitude sites are infrequent since they are unable to complete their life cycles and compete effectively.

Low temperature produces slow growth, poor nutrient uptake, and results in low annual biomass production. Native species seem better adapted physiologically than agronomic species though are infrequently used in reclamation due to poor availability of seed.

Windthrow and frost heaving often hinder the establishment of grass or tree cover and are both related to soil characteristics.

Due to the poor nutrient status of most sites, the initial establishment of growth is dependent upon the addition of fertilizer, particularly nitrogen. Nutrients taken up by the plants are only slowly recycled in available forms. The poor response of commercial legumes, especially above the tree-line, puts further strain on the nitrogen economy of reclaimed sites at high altitude.

Therefore, to avoid erosion and successfully revegetate mountainous areas, careful consideration should be made of the physical and chemical characteristics of all potential soil materials on hand.

TYPES OF SAMPLES

Soil samples presented to the laboratory may be generated from many different sources and for many different reasons. However, in terms of land reclamation, the following categories may be identified:

1. Soil survey of undisturbed surface terrain prior to disturbance.

2. Inventory of surficial deposits.

3. Deep coring programs as part of exploratory phase.

4. Rock, overburden, tailings and other wastes generated during mining and processing of coals, ores, etc.

5. Samples from monitoring of partially reclaimed areas.

Soil samples from inventory and soil survey work are most frequently those that will be used to plan future reclamation of disturbed areas. The data obtained is generally of most use if presented in the form of a map either using the classical soil surveying descriptions or for more site specific use to show topsoil depths, textural distribution, erodibility, etc. With recent advances in data handling using computer linked printer-plotters, the direct transfer of soil data onto base maps will become more common.

The particular types of analyses carried out will depend upon the nature of the sample and the purpose of its collection. There must be a good reason for each analysis and the information gathered should help meet some practical objective. Despite this obvious statement of common sense, it is evident that sometimes we are guilty of over-analyzing rather than under-analyzing soils.

PHYSICAL CHARACTERISTICS

Physical characteristics of the soil are probably more important than chemical or biological properties in the reclamation of disturbed mountainous areas. While admittedly vegetative cover is an integral part of soil stabilization, the correct management of physical characteristics of the disturbed surface will largely make or break the success of reclamation.

Physical measurements are concerned with the evaluation of erodibility, moisture storage, compaction, aeration and the behaviour of soil under load at different moisture conditions on variable slopes. Certain measurements involving structural, textural and permeability characteristics may be made in the field while others can be made with more precision under laboratory conditions.

Physical measurements may include particle size distribution, bulk density, particle density, porosity, water storage capacity, consistence and surface resistance. The close relationships between many of these characteristics mean all the analyses need not be measured on all samples.

PARTICLE SIZE DISTRIBUTION

For agricultural purposes, texture and particle size distribution are described in terms of the distribution of coarse fragments (>2 mm diameter) and of particles less than 2 mm in diameter, the latter being sand (0.05 mm to 2.00 mm diameter), silt (0.002 mm to 0.05 mm diameter) and clay (<0.002 mm diameter). Sands and silts may be further sub-divided.

In mountainous areas, the coarse fragment content may often exceed the volume of the smaller particles so that some adjustment of the normal agricultural interpretations is needed. A high coarse fragment content increases permeability and aeration of dense soils. However, the favourable effects on plant growth are said to be outweighed beyond about 20% by volume coarse fragment content (Lutz and Chandler 1946). At greater coarse fragment contents, the moisture holding capacity of the soil is reduced and the amount of mineral soil available to root growth becomes proportionately too small.

Some inaccuracies in methodology are likely when particle size distributions of mine spoils are measured (Ames 1980). Most procedures are based upon sedimentation rate calculations in water and assume spherical particles with a mean density of 2.65 g/cm^3. Many mine spoils may have particle densities well over 3 g/cm^3 (e.g. Como et al 1978) which will result in slight overestimations in sand and possibly silt fractions unless the Stokes Law constants are modified. In addition, further problems may be encountered from poorly wettable materials, predominance of linear particles, particles with densities less than water and poor dispersion with very saline spoils. All require modification of the standard procedures to obtain reliable results.

The relative distribution of the finer particles affects many soil characteristics. The relative effect on surface phenomenon may be appreciated if one realizes that the surface area per cubic meter increases from about 7 ha in sand to about 140 ha for silt and 1400 ha for clays. Most chemical and biological reactions in soils occur in the film of water around soil particles.

The total pore space and the relative pore size distribution is largely determined by the particle size distribution though it is modified by aggregation of primarily particles and the presence of organic materials. Sandy soils have large pores which do not restrict infiltration and percolation of water. Clay soils have a large total pore space but have predominantly very fine pores which result in poor infiltration and aeration. Loamy soils with a balanced distribution of sand, silt and clay sized particles (see Figure 1) have a wider distribution of pore sizes which allows for adequate permeability and aeration.

It may be appreciated that information on texture and particle size distributions may be used to estimate moisture storage, infiltration, erodibility, frost and windthrow hazards, nutrient holding characteristics, buffering capacity and many other characteristics of a soil.

BULK DENSITY

The bulk density, or oven dry mass per unit volume, of an undisturbed field soil is important in several respects. The volume that a soil occupies includes the volumes of soil particles, and air or water filled pore space. Therefore, by determining the mean particle density and bulk density, we may also determine porosity since:

$$\text{Porosity, } P = 1 - \frac{D_B}{D_P}$$

where D_B = bulk density and D_P = particle density.

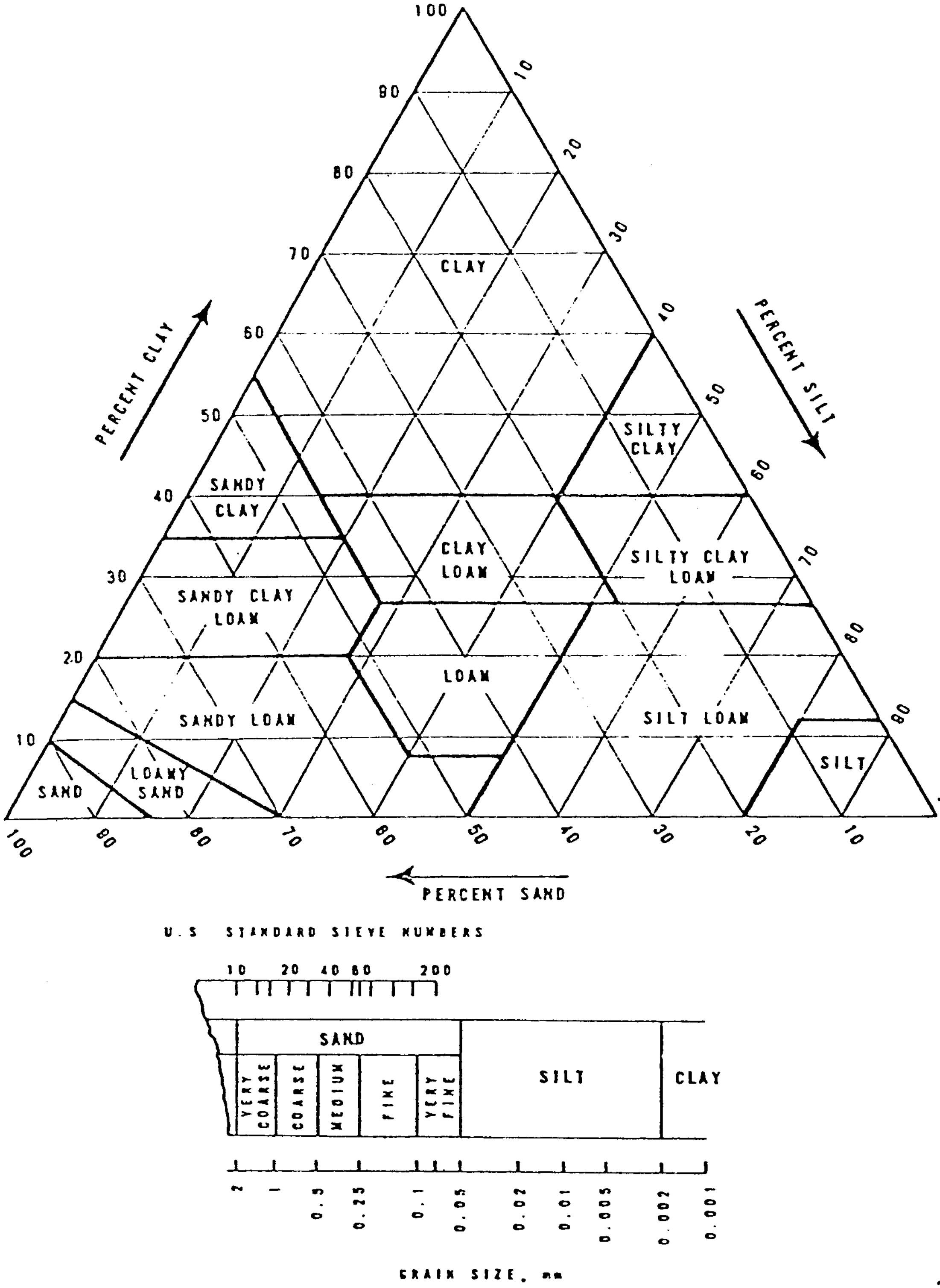
Since soil densities may vary widely (see Table 1), it is essential that field bulk densities are determined to convert mass based data in units of ppm, %, etc., into data of an area nature, e.g., Kg-N/ha, cm water stored/ha, etc.

TABLE 1: APPROXIMATE BULK DENSITY RANGES FOR DIFFERENT SOILS AND RELATED MATERIALS

MATERIAL	BULK DENSITY (g/cm^{-3})
Moss cover (Sphagnum)	0.04
Undecomposed peat	0.10
Organic duff layers	0.20
Tilled mineral soil	0.80
Surface mineral horizons	1.1 - 1.4
Compacted subsoils	1.6 - 1.9

FIGURE 1

SOIL TEXTURAL DESCRIPTIONS BASED ON
DISTRIBUTION OF SAND, SILT AND CLAY FRACTIONS



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Bulk densities of 1.6 g/cm^3 to 1.7 g/cm^3 and above are commonly considered so dense as to impede penetration and enlargement of roots.

MOISTURE STORAGE

Moisture storage in the surface 1 m to 1.5 m of the soil is most critical to plant survival.

Water in unsaturated soil is prevented from draining by forces that result from surface tension and cohesion of water molecules, the adhesions of water molecules to soil surfaces and from electrostatic forces at the inter-molecular level. The amount of water available for plant growth will depend upon the total water content of the soil and absorptive properties related to particle size distribution, organic matter content, and the structural stability of the soil.

To determine the moisture retaining characteristics of the soil, the amount of water held at different suctions is measured. Suction is commonly expressed in terms of bars (10^6 $dynes.cm^{-1}$), approximately equivalent to atmospheres. The characteristic shape of the curve produced is largely related to the particle size distribution of the mineral fraction of soil. The upper and lower limits of moisture availability to plants are usually arbitrarily set at 0.3 bar (field capacity) and 15 bar (permanent wilting point). Field capacity is the point at which the rate of removal of water from a saturated soil due to drainage begins to be reduced. Availability of water to the plant at lower suctions can be thought to be unrelated to the soil but dependent upon root interception of water in a hydroponic situation. The permanent wilting point is the moisture content at which plants can no longer obtain sufficient water from a dry soil and begin to irreversibly wilt. It is not surprising that considerable variability exists between plant species in terms of the wilting point though 15 bar is a practically oriented mean value for most agricultural crops. At the lower end, field capacity is better set at about 0.10 to 0.15 bar for sandy soils and at 0.5 bar for heavy textured clay soils.

The favourable pore size distribution of soils textured as loams, silty loams and silty clay loams give them superior moisture storage and release characteristics in comparison to clay-rich or sandy textured soils. Christie (1980) in this meeting last year presented a useful figure relating moisture storage to texture and coarse fragment content. It is also important to note that sandy soils do not just have poor moisture storage but also have little "moisture loss buffering" and they reach wilting point very rapidly under drying conditions in the field.

CONSISTENCE AND SURFACE RESISTANCE

Atterberg's limits are indexes of consistency or workability and firmness of soils at different water contents. They have agricultural and engineering application in showing us the ease of working soils in terms of machinery power requirements, the likelihood of destroying soil structure and the possibility of slope failures.

The plastic limit is the lowest moisture content at which the soil can be deformed without cracking. The liquid limit marks the moisture content where the soil becomes semi-fluid in consistence. The difference between these upper and lower plastic limits, called the plastic index, gives an indication of clayiness or plasticity of a heavy textured soil.

Surface resistance, which is also related to soil texture, can be studied by penetrometer measurements in the field or by determining the modulus of rupture in the laboratory. The latter, which is a measurement of the cohesion and strength of dry soil may provide useful information on surface crusting of soils (Richards 1953).

WATER PERMEABILITY

Infiltration rate, permeability and drainage are all related terms used to assess water movement through soil and predict groundwater flow patterns.

Permeability is often equated with hydraulic conductivity, as the rate at which water is transmitted through saturated soil, a condition infrequently encountered in the field. Infiltration rate refers to the entry of water under unsaturated conditions. Drainage is a term used more with the plant component included and describes the ease of water loss from the rooting zone.

Water movement depends upon texture, structure, the presence of impermeable layers, the ionic constituents of the soil solution, the nature of the vegetative cover and its rooting characteristics. Consequently, the accurate measurement of water movement through soils is a field measurement. Hydraulic conductivity and infiltration are often measured using double ring infiltrometers (Bertrand 1965).

It may be appreciated that physical measurements can be used to study many features of practical importance in reclamation planning. By example, I will briefly discuss erodibility predictions since they are important in disturbed mountainous terrain.

EROSION HAZARD PREDICTION

Landscape erosion produced by the action of wind and water is governed by the interrelationships of climate, vegetation, topography and soils. We have little control over climate but are able to manipulate the remaining three within fairly wide boundaries constrained only by the materials at hand, the compatibility of the vegetation and, as always, cost. With some foresight, we should be able to devise soil survey and analytical programs to provide information needed to predict erodibility under several different mining alternatives. Basic soil data needed will relate to moisture holding capacity, infiltration/permeability and soil consistence.

Resistance to erosion is largely related to the stability of soil particles and aggregates, and the way water infiltrates or runs over the soil surface. Soils high in very fine sand or silt are especially susceptible to erosion. Sandy soils which do not have the necessary fine material or organic matter to bind particles together are unstable to both wind and water. Soils with moderate amounts of clay and organic matter develop secondary aggregates which resist detachment from the soil surface.

Vegetative cover affects physical deterioration of soil through interception and absorption of rainfall and shielding surface from the direct impact of wind. The effectiveness of the vegetation depends upon coverage of the ground, thickness of the vegetative layer and the stabilizing effect of rooting.

Water infiltration into soil is dependent upon permeability and drainage characteristics. High surface infiltration reduces runoff but will be destructive if soil drainage is poor due to bedrock, non-wettable layers, hardpans or compacted layers, etc. near the surface. There have been various attempts to relate steepness and slope length to erodibility. A practical statement seems to be that where the vegetative cover, including litter, is less than 50%, the erosion rate doubles for each 10% (5°) increase in slope (Meeuwig 1971). Generally, slopes in the 60% to 70% (30° to 35°) range and greater are considered to be internally unstable as well as difficult to revegetate. Doubling the length of slope seems to inorease erosion by a factor of 1.5 to 3 times (Rothwell 1971, Wischmeier and Smith 1978).

The assessment of erosion hazard shown in Table 2 is provided as an example. It was developed for potential use in commercial forestry for designing logging management and roadway construction and so contains elements not so relevant to reclamation. However, similar schemes could be developed for site specific use by modifying the characteristics used and providing a numerically weighting scoring system rather than the "very low" to "very high" rating.

TABLE 2. ASSESSMENT OF EROSION HAZARD

	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH
Texture	Gravel	LS, cSL	C, SiC, SiCL, fSL, SCL, CL, L	SiL	Si, fS
Slope	0-15%	16-30%	31-45%	45-70%	70% +
Erosional Processes	Not				Active Present
Depth to Impermeable Layer	3 m +	1-3 m	50-100 cm	20-50 cm	20 cm
Permeability	Very Rapid	Rapid	Moderate	Slow	Very Slow
Drainage	Rapidly	Well to Moderately Well	Imperfectly	Poorly	Very Poorly
Duff Thickness	20 cm +	10-20 cm	2-10 cm	2 cm	No Duff

Adapted from Vold, 1981

CHEMICAL CHARACTERISTICS

Whereas standard analysis of physical properties of soils have had wide application both in engineering, agriculture and land reclamation, more specialized chemical testing methods have been developed for the evaluation of farm soils. It has been unfortunate that many agricultural methods have been used without sufficient thought as to how the analyses can best be applied to land reclamation problems.

As was noted previously, testing of the fertility status of farm soils has been refined for annual crops which often obtain most of their nutrients within the first 6 to 8 weeks of seeding. Generally, the methods involve the use of a variety of chemical extractants that are designed to bring particular elements into solution in an amount that is in some way proportional to plant uptake during the forthcoming growing season. Chadwick (1973) has pointed out that extraction methods are based upon an assumption that the solution comes into a rapid equilibrium with the solid soil phase, an assumption that may often be untrue with poorly buffered mine spoils. Also, as a more general observation, it seems that in mine reclamation we are equally interested in usefulness of mixtures of potential growth materials as with the individual soils on hand. This tends to place more emphasis on long term interactions as opposed to the short term fertility assessments that we are familiar with in agriculture.

pH

The relative acidity or alkalinity of a soil is generally viewed in terms of plant growth. The optimum pH range proposed depends on the preferences of the vegetation. A pH of about 6.5 is generally the "agricultural optimum" while pH in the 5.0 to 5.5 range may be considered as one "forestry optimum." However, soil pH is also a broad indicator of soil chemistry as well. The following are diagnostic:

pH below 5.0 - Calcium, magnesium, potassium and phosphorus low in solubility while most heavy metals become more soluble. Soluble aluminum and manganese may be present at levels toxic to plant roots.

pH 5.5 and above - Reduced solubility of heavy metals, aluminum and manganese unlikely to be toxic.

pH 7.8 to 8.2	- Soil liable to contain calcium carbonate and increasing concentration of soluble sodium.
pH 8.5 and above	- Soil liable to contain sodium as the carbonate, bicarbonate and sulphate, with the possible development of sodic problems requiring the addition of calcium.

The usefulness of pH measurement may be in determining the effect of mixing different soil together in reducing metal toxicities, reducing acidity, or improving soil structure and water permeability.

SOLUBLE SALTS

The electrical conductivity (EC) of a saturated soil extract is normally used to assess the soluble salt content. Where a soil is found to be sodic, the saturated extract is often used to determine the sodium absorption ratio (SAR*). Interpretation of EC data relies heavily on the "2-4-8-16" table presented in the USDA Handbook No. 60 (Richards 1954), where 4.0 mmhos/cm is generally considered to be the good/bad borderline (see Table 3).

TABLE 3. INTERPRETATION OF ELECTRICAL CONDUCTIVITY

<2 mmhos	No salinity problems
2-4 mmhos	Restricts the growth of very salt sensitive plants
4-8 mmhos	Restricts the growth of many crops
8-16 mmhos	Restricts the growth of all but salt tolerant crops
>16 mmhos	Only a few salt tolerant crops make satisfactory yields

These guidelines are useful but for our purposes several other factors must also be considered.

$$*SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

Where concentrations are in milliequivalents per liter of extract.

The relative tolerances of different plant species vary quite widely. The same plants at different stages of growth show variable sensitivity to salt. The effect of different ionic species creating the salt load may vary widely in terms of toxicity or creating ionic imbalances. Also, low EC values may apparently not affect cover but may reduce yield. The latter is quite important where disturbed areas are being returned to a former agricultural use as may be the case in surface coal mining or pipeline construction in the Great Plains area. Table 4 summarizes data for a range of agricultural crops.

TABLE 4. EFFECT OF ELECTRICAL CONDUCTIVITY ON CROP YIELD

	EC REQUIRED TO PRODUCE THE STATED YIELD REDUCTION (mmhos/cm)		
	0%	25%	100%
Forage Crops	1.5 - 7.5	3.6 - 13.3	10 - 32
Field Crops	1.7 - 8.0	3.8 - 13.0	10 - 28

Adapted from EPA, 1977.

Finally, the EC is not static but fluctuates with changes of water movement through the soil and with evapotranspiration characteristics. An initial high salt content may be tolerated in a well drained soil due to gradual leaching of the salt, while in arid or semi-arid climates, salts may move from depth and accumulate with time in surface horizons.

ORGANIC MATTER

The importance of organic matter in maintaining soil productivity through its effects on nutrition, structure and water holding is universally acclaimed. However, when we attempt to define minimum or optimum levels of organic matter for reclaimed soils, we run into trouble unless we look at the quality aspects as well. Desirable values within the 1% to 10% range have been suggested for agricultural, forestry and reclamation purposes (Nishimura 1974, Omodt et al 1975, Alberta Soils Advisory Committee 1979, Wilde et al 1972, van den Dreissche 1979).

But what is the quality of organic matter and how do we measure it? Certainly we realize that the organic materials in coal, tar sand, peat or the Ah horizons of a Chernozemic soil are not the same. Their benefit to reclamation bears no relationship to their organic carbon content which is the current way of determining the organic matter content of soil. Unfortunately, soil chemists in the past 100 years have produced a weighty literature discussing organic matter fractionation but have yet to explain its relationship to soil fertility. In mine reclamation, especially in the coal industry, an apparently desirable level of organic matter of largely inert coal-like carbon is included in the seedbed material without evidence to suggest any usefulness in nutrient cycling, moisture retention and the development of "the self-sustaining vegetative cover."

In addition, the methodologies available for determining carbon in soil which range from a variety of wet chemical procedures to the "Leco" dry combustion, vary in their effectiveness in oxidizing different types of organic carbon structures and in discriminating between organic and inorganic forms of carbon.

CATION EXCHANGE CAPACITY

The cation exchange capacity (CEC) is the amount of cations, usually in milliequivalents per 100 g, that a soil is able to hold due to attraction to negatively charged sites on the surfaces of clays, organic matter and hydrous oxides of iron and aluminum. Cations most commonly held are calcium, magnesium, potassium, sodium, aluminum, hydrogen, ammonium and, to a lesser extent, iron, manganese, zinc, copper and other metallic ions.

When asked what the significance of CEC in soils is, we normally answer that it is related to the retention of nutrients and in preventing their leaching from the soil. However, in reality, we probably place importance on CEC as a soil characteristic due to its direct relationship to organic matter and clay contents (see Table 5). In view of this and the analytical problems associated with its measurement, it is probably an unnecessary measurement as an initial assessment of soil characteristics. Rather than consider a CEC of 5 to 10 me/100 g as a minimum for reclamation, we would be better to set standards for clay and organic matter.

TABLE 5. APPROXIMATE RANGES OF CATION EXCHANGE CAPACITY

	CEC (me/100 g)
Sandy soils	1 - 10
Silt loams	12 - 20
Clay loams, clays and organic soils	> 20

The measurement of CEC is pH dependent since the negative charges associated with hydrous metal oxides and organic matter result from the dissociation of hydroxyl and carboxyl groups. Commonly, CEC is measured by the displacement of cations by a strong salt solution at a pH of 7.0. However, for the most realistic results, if we are really wanting to measure the cation absorptive power, it should be measured at the natural pH of the soil. In acidic soils, for instance, CEC measured at natural pH can be expected to be considerably less than that measured at neutrality. In addition, depending upon the particular method used, the measurement of individual exchangeable cations can be greatly over-estimated in soils containing high concentrations of soluble salts or free lime. This is of some importance since many researchers believe that it is not necessarily the absolute concentration of exchangeable cations that is important in plant nutrition but the relative abundance of different species. Parnes (1978), for example, suggests an optimum balance of 70% calcium, 12% magnesium, 2% to 5% potassium (depending upon texture) and the balance largely as hydrogen. Other guidelines have Ca, 60% to 70%; Mg, 20% to 35%; K, 5% to 10%; and Na, less than 5% (EPA, 1977). By comparison, proposed absolute amounts vary widely depending upon the worker and plant types concerned, e.g. Ca, 100 ppm to 1600 ppm (0.5 to 8 me/100 g); Mg, 25 ppm to 250 mm (0.2 to 2 me/100 g) and K, 25 ppm to 150 ppm (0.07 to 0.4 me/100 g) (Doll and Lucas 1973, Wilde 1964b, van den Driessche 1979). Apparently, quite a wide variation in Ca:Mg is tolerated and probably adequate growth occurs unless Mg exceeds Ca on an equivalent basis or if Mg makes up 50% or more of the exchangeable bases.

SODIUM

As noted previously, when sodic conditions are indicated, it is common to determine the sodium absorption ratio (SAR) on the saturated extract. The SAR was originally developed to assess irrigation water and has become commonly used to study saline soils as well. Probably the exchangeable sodium percentage (ESP), the percentage as sodium making up the whole CEC, is more correctly applied to soils. However, ESP and SAR do show a well defined relationship within the ranges normally encountered for soils (see nomographs in Richards 1954).

A critical value for SAR is normally set at 9, the point where dispersion of clay minerals is liable to cause development of poor structural conditions and impaired drainage. However, it is likely that initiation of structural deterioration can be below this value depending on textural and aggregational differences. More realistic values using ESP have been set as follows:

< 5%	Satisfactory
> 10%	Liable to produce reduced permeability in fine textured soils
> 20%	Liable to produce reduced permeability in coarse textured soils

(EPA, 1977)

MAJOR PLANT NUTRIENTS

In disturbed areas, the question of the future nutrient status of the soil is at least equally important as the current condition of the seed bed. This brings into account time dependent aspects of weathering which may be greatly accelerated if previously buried materials are exposed and mixed at the land surface. We have to consider whether it is possible or even desirable to use testing methods to make fertilizer recommendation and to assess whether the testing methods are valid in a non-agricultural setting. A short discussion of testing for potassium, phosphorus and nitrogen is presented.

Potassium

Potassium analysis illustrates the concept of soil testing well. Most soils contain large quantities of the element potassium but only a small percentage, perhaps 1%, is in exchangeable form on the soil colloids and even less, a few ppm, is in the free soil water or soil solution. These different phases of potassium are in chemical equilibrium so that potassium removed by plant roots is replenished. Most soil potassium is in primary minerals such as potassium feldspars, muscovite and biotite micas. These minerals release potassium very slowly by physical and chemical weathering. Some potassium is found within secondary clay mineral structures such as illite, vermiculite and chlorite, and is released slowly. Most of the remaining potassium is held on exchange sites with smaller amounts in the soil solutions and in these forms can be considered actively involved in plant uptake. Thus, conceptually, we consider soil potassium being divided into unavailable, slowly available and readily available forms. In agricultural assessments, it is normally found that exchangeable potassium, including solution-K, is directly related to plant available potassium. Therefore, the ammonium acetate extraction to measure exchangeable cations is used to provide an index of available soil potassium. Although it is probably an adequate test for available potassium in most cases, the use of a stronger acidic extractant that simulates chemical weathering may provide a better estimate of the long term potassium releasing characteristics of mine spoils.

Phosphorus

Study of the available phosphorus status of soils is difficult due to the complexity of soil phosphorus chemistry. Phosphorus forms sparingly soluble compounds with divalent and trivalent ions. Calcium phosphates are common in neutral and basic soils while iron and aluminum phosphates predominate in acidic soils. As with potassium, the amount of phosphorus present in the soil solution is very small but following plant uptake replenishment can be rapid. Soil testing methods have been developed which provide an index of availability by extracting solution phosphorus plus a fraction of non-solution phosphorus. Two different extractants are used in Western Canada: the Bray Reagent (0.025 N hydrochloric acid:0.03 N ammonium fluoride or slight modifications) for acidic to mildly basic soils and the Olsen Reagant (0.5 N sodium bicarbonate, pH 8.5) for more basic soils. Since the Bray Reagent extracts about three times the amount of phosphorus than the Olsen Reagent from soils of equivalent fertility, the methods have had to be specifically calibrated. Reclamation reports often omit to state precise methodology, an important point since numerically the data are not equivalent.

Although these test methods are probably of some use in land reclamation work, their relevance to longer term aspects of nutrient cycling and phosphorus economy in disturbed soils is more doubtful. Study of the transformation or "turnover" of organic phosphorus may be more instructive.

Finally, the measurement of phosphorus absorption is most important in determining the fate of phosphorus fertilizers added to disturbed mine soils. In certain mine spoils with high absorption capacity, much of the added phosphorus could be fixed in a form largely unavailable to plant growth. In such cases, addition of more frequent small doses of phosphorus may be more effective to build up the phosphorus status of the site to acceptable levels. Methods for the measurement of phosphorus absorption capacities are described and discussed in Como et al (1978) and Enfield and Bledsoe (1975).

Nitrogen

In most surface soils, from 97% to 99% of the nitrogen is in organic form and must be mineralized by soil micro-organisms into plant available mineral forms. Being a biological process, the rate of nitrogen mineralization is largely dependent upon soil pH, temperature and aeration. The rate and net release is also dependent upon the nature of the organic materials in the soil. Net release or mobilization is favoured by narrow carbon:nitrogen content ratios (e.g., 20:1 and lower) in the organic matter. Decomposition of fresh plant residues high in cellulose, hemicelluloses and lignin but low in nitrogen may result in immobilization of available nitrogen into microbial tissues and deficiencies in plant growth.

Mineralization results in the formation of nitrogen as ammonium ions. In all but the more acidic soils, ammonium-N is "nitrified" into nitrate-N via the usually transitory intermediate nitrite. Ammonium can be held on the exchange complex while the nitrate anion may leach downwards in humid well drained soils and be lost below the rooting zone. Under warm water-saturated conditions, nitrate may be "denitrified" into gaseous forms of nitrogen by anaerobic bacteria and lost from the soil surface.

Since nitrogen is the most common element that limits plant growth, it rarely accumulates to any great extent. Soil testing by measuring nitrate and/or ammonium is generally only successful in predicting the nitrogen requirements for annual crops. In humid areas where nitrate may be leached below the sampling zone, even the nitrate test for annual crops is unreliable. Applying this knowledge to land reclamation, we might expect reasonable usefulness from the measurement of mineral nitrogen levels prior to seeding prepared bare soil surfaces. However, we may be better advised to measure an index of the nitrogen supplying of potential soil mixes to show potential nitrogen fertility over a longer time span. "Mineralizable" nitrogen tests have found some success in assessing potential fertilizer responses in commercial forestry (Shumway and Atkinson 1978), a setting not dissimilar from many of our disturbed sites. In general, the anaerobic mineralization method (Waring and Bremner 1964) gives best results since it is convenient for soils varying widely in moisture holding capacity. It could conceivably be used to show changes in nitrogen cycling patterns with time but would require calibration to relate laboratory values to the potential release of nitrogen under field conditions.

WEATHERING AND THE RELEASE OF METALS

Probably little useful information can be derived from studying simulated weathering of undisturbed soils due to their inherent stability. However, estimates of weathering and induced chemical change are most important in disturbed sites, particularly where subsoils are exposed or where sulphide tailings present potential problems of heavy metal release as acidity is generated.

Several weathering methods may be useful to study physical or chemical weathering. However, insufficient research has been carried out on disturbed soils to indicate the best methodology or the practical interpretation of the data.

Field methods are generally too slow while laboratory simulations pose problems of relating lab time to field time scales. Henin and Pedro (1965) used a standard Soxhlet continuous extractor to study the weathering of rock fragments. The method enables study of both aerobic and anaerobic zones simultaneously by varying liquid levels of gas mixtures in the apparatus. A similar method was used by Como et al (1978) in studying weathering of metal tailings from mines in British Columbia. Accelerated weathering of minerals and organic materials used in the revegetation of tar sand tailings has also been studied using cycles of laboratory incubations interrupted by freeze/thaw cycles to simulate overwinter conditions (Rowell 1980).

Ultrasonic treatment has been used to study physical weathering of soft rocks (Overby and Henniger 1969, Laguros et al 1974) but has not been used for land reclamation studies. Using coarsely crushed Oklahoma shales, Laguros and co-workers estimated that one hour of ultrasonic treatment of 200 W at 20 kc and 70°F was equivalent to two years of field weathering. Changes were measured in particle size distribution and in liquid and plastic limits.

A rather straightforward but tedious method is described by Massey and Barnhisel (1972) where mine spoils were moistened to 1/3 bar and after a period of incubation were subjected to 15 bar suction to remove much of the soil water. Incubation cycles were repeated and the soil extracts produced were analyzed for metal release.

Alternate assessments of acid production from sulphide tailings have been discussed by Grube et al (1974). Lime requirements based on sulphur content were claimed to be valid if soluble sulphate was removed by acid washing, and presumably if weatherable basic constituents in the tailings were taken into consideration. Theoretically, we may calculate that tailings containing 0.1% of total sulphur as sulphide, and with a bulk density of 1.5 g/cm^3 would require 468 kg of lime per cm depth per hectare to neutralize potential acidity. However, the real lime requirements would depend upon the rate of acid production and the effect of incorporating other amendments on both the acid buffering capacity and the rate of acidification.

It is important to stress that conventional lime requirement testing based on soil pH, buffer methods or incubation with liming materials will only indicate current lime requirement and will not take into account future acidity produced. As an example, Maclean and Dekker (1976) carried out growth chamber experiments on acid mine spoils that were limed according to rates obtained by incubations with lime. Initially the plants grew well but by the end of the experiment, the soils were very acidic again and required further liming. Similar cautionary tales are provided by Nyborg (1974) working on soils affected by sulphur dustfall from gas processing plants in Alberta.

Potential problems from acidic mine wastes arise not just from the effect of acidity on plant growth but from solubilization of metallic ions and their transport into the food chain via plants or drainage water.

In small doses, potential benefits could arise from increases in available copper, boron, molybdenum, zinc, cobalt and selenium which are deficient in some soils. However, the amount needed to correct deficiencies is generally quite small, for example, in the 25 kg/ha range for copper and zinc, less than 2.5 kg/ha for boron and less than 0.4 kg/ha for molybdenum.

Considerable confusion exists as to what the critical levels are for different metals in soils. Standard methods to indicate their availability to plants are less well developed than for the major elements. Metal chemistry in soil can be complicated and may involve fixation of metals as complexes and chelates with the humates and fulvates derived from humus, precipitation reactions as carbonates, sulphates and phosphates, absorption onto clay minerals, humus and hydrous oxides of iron, aluminum, manganese and silica, etc.

The relative solubility and toxicity is also related to the metal's valence state, red/ox conditions and to soil pH. Chromium IV, for instance, is very toxic but under normal conditions it occurs in the III state which is insoluble and much less toxic.

Liming acidic soils, mine spoil, and tailings will increase pH and generally reduce the availability of aluminum, cadmium, cobalt, fluoride, iron, manganese, nickel and zinc, and to a lesser extent, copper and boron. Liming tends to increase the availability of calcium and magnesium (often both present in the liming material as well), and molybdenum, phosphorus and potassium. Therefore, if we wish to produce guidelines for potential metal toxicity, we should take into account soil pH.

Methods for the appraisal of potential metal toxicity in soil have not been standardized. They range from a total elemental analysis to extraction methods involving chelates or weak acids that are hoped to extract a fraction of the total in some numerical relationship to plant uptake. A method that provides an index of potentially weatherable metal concentration, possibly that removed by 2 M HCL at 100°C, may be useful in mine reclamation assessments.

As can be appreciated, the interpretation of data can be very difficult. In many instances, the plant root seems to act as a barrier against excessive uptake and may bear no relationship with total elemental concentrations in the soil. Often, critical levels are developed for plants in growth chamber experiments by defining the concentration required to produce, for example, a 25% yield reduction. However, the results do not take into account metal interactions, differences in chronic effects, subtle genetical or physiological changes, or the impact on animals eating the plants. Chumbley (1971) proposed for zinc, copper and nickel that the maximum additions to soils, at a pH above 6.5, should not exceed 250 ppm or the weighted equivalents of all three combined. For this purpose, copper was considered twice as toxic as zinc and nickel eight times as toxic as copper.

A comparison of proposed guidelines for soil is presented in Table 6. The loading rates quoted from EPA, 1977, were proposed for use in rapid infiltration effluent disposal systems where the soils would be freely drained and rather low in clay and organic matter.

TABLE 6. SOME PROPOSED GUIDELINES FOR METAL ADDITIONS TO SOILS

	NATURAL LEVELS (ppm)		GUIDELINE LEVELS (ppm)	
Element	Mean	Range	I	II
As	6	.1 - 40		13
Cd	.06	.01 - .07	5	1.4
Cr	100	5 - 3000	47	56
Cu	20	2 - 100	90	100
Hg	.03	.01 - .3		0.05
Mo	2	.2 - 5	5	1.6
Ni	40	10 - 1000	90	43
Pb	10	2 - 200	2285	56
Zn	50	10 - 300	920	216
Al			2285	1*
B			340	
Co			23	18
Fl			460	
Fe			2285	
Mn			90	20*
Se			9	1.6

*Soluble in 0.01 M $CaCl_2$.

I - Adapted from EPA, 1977.
II - Alberta Soils Advisory Committee, 1979.

CONCLUDING REMARKS

In land reclamation, the soil scientist is presented with many new problems and challenges. The wide array of chemical and physical tests already developed for engineering, agriculture and forestry may have a direct application to land reclamation problems. However, the study of many soil characteristics may require the modification of existing methods or the development of new procedures to cover the field from mine spoils to tailings.

The way we use the results must depend on clearly defined objectives for each phase of reclamation to the final land use. The soil characteristics and qualities that we define as optimum or minimum for one purpose may differ widely from another land use alternative. In addition, the initial objectives of reducing erosion and maintaining water quality may conflict with soil requirements for the final proposed use of the land.

Where we attempt to return disturbed agricultural and commercial forestry areas to a state at least equal in productivity, considerable forethought will be required. If we are unable to attain a stable state of soil quality and productivity, we must consider the soil to have been degraded and reclamation to have failed.

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LIST OF SYMPOSIUM REGISTRANTS

MR G B ACOTT
CARDINAL RIVER COAL
BOX 2570
HINTON ALTA
T0E 1C0

MR T A B ADAMSON
UNION OIL CO OF CANADA
335 8 AVE SW
BOX 999
CALGARY ALTA
T2P 2M7

MR ROBERT AIELLO
FIELD COORDINATOR
CROWS NEST RESOURCES LTD
BOX 2699 STN M
CALGARY ALTA
T2P 2M7

MR DAVE ALDRIDGE
MIN OF HIGHWAYS
1011 FOURTH AVE
PRINCE GEORGE BC
V2L 3H9

MR F A ALLEN
202 2025 BELLVIEW AVE
WEST VANCOUVER BC
V7V 1B9

MRS CLARA ANDERSON
BOX 205
JUNCTION CITY ORE
USA

MR DARWIN ANDERSON
DEPT OF SOIL SCIENCE
UNIV OF SASKATCHEWAN
SASKATOON SASK

MR JOHN AUSTIN
KLOHN LEONOF
10180 SHELLBRIDGE WAY
RICHMOND BC
V6X 2W7

MR BOB BAASE
CRAIGMONT MINES LTD
BOX 3000
MERRITT BC
V0K 2B0

MR BRENT BAILEY
NORANDA MINING CO
BOX 1564
SALMON ID
USA 83967

MR T S BAILIE
GENERAL MANAGER
CANADIAN SEED COATERS LTD
BOX 219
BRAMPTON ONT
L6V 2L2

MR ROBERT E G BAKER
MIN OF ENVIRONMENT
1617 BAKER ST
CRANBROOK BC
V1C 1B4

MR A BALLACHY
FIBRAMULCH
16315 117 AVE
EDMONTON, ALTA
T5M 3V3

MS WENDY BATES
SUNSHINE VILLAGE
BOX 1510
BANFF ALTA
T0L 0C0

MR PETER BECKETT &
MS BRIGITTE ANGSTER
10 2 RAMSAY LAKE RD
SUDBURY ONT
P3E 2C6

MR R BELYEA
ONTARIO HYDRO
700 UNIVERSITY AVE
TORONTO ONT

MR ROGER BERDUSCO
FORDING COAL LTD
BOX 100
ELKFORD BC
V0B 1H0

MR ED BESWICK
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
2747 E HASTINGS ST
VANCOUVER BC
V5K 1Z8

DR M J BIK
BOX 1993
STATION M
CALGARY ALTA
T2P 2M2

MR T BODNARCHUK
MIN OF HWYS
310 WARD ST
NELSON BC
V1L 5S4

MR R BONE
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
BOX 1290
FERNIE BC
V0B 1M0

MR GORDON T BOUTILIER
CAPE BRETON DEVELOPMENT CORP
BOX 1750
SYDNEY NS
B1P 6T7

MR JOHN BOYLE
ENVIROCON LTD
300 475 W GEORGIA ST
VANCOUVER, BC

DR MICHAEL BRETTON
810 WEST
BOX 1498
KALLISPELL MONT USA 59901

MR CURTIS BRINKER
ALBERTA ENVIRONMENT

MR JOHN BRODIE
KER PRIESTMAN & ASSOC
300 2659 DOUGLAS ST
VICTORIA BC
V8T 4M3

MR BERNARD BROOKS
NORANDA MINES LTD
BOX 4000
NORANDA QUE
J9K 5B6

MR ALISTAIR BROWN
SCHULTZ INTERNATIONAL LTD
1155 W GEORGIA ST
VANCOUVER BC
V6E 3H4

MS JILL BROWNE
106 9947 SASKATCHEWAN DR
EDMONTON ALTA
T6E 4R3

MR JIM BUCKINGHAM
SUNSHINE VILLAGE
BOX 1510
BANFF ALTA
T0L 0C0

MR C W B BURGE
LORNEX MINING LTD
BOX 10335
1650 609 GRANVILLE ST
VANCOUVER BC
V7Y 1G5

MS CECIL BURNS
ONTARIO MIN OF ENVIRONMENT
808 ROBERTSON ST
KENORA ONT

MR ART BURROWS
SUPERVISOR LAND ADMIN
COMINCO LTD
SULLIVAN MINES
BOX 2000
KIMBERLEY BC
V1A 2G3

MR L T L CALLOW
GULF CANADA RESOURCES INC
BOX 130
GCS 15 FL
CALGARY ALTA
T2P 2H7

MS JANET CAMERON
80 RANGEWAY NW
CALGARY ALTA
T3G 1H4

MR JOE CARAVETTA
CROWS NEST RES LTD
BOX 2003
SPARWOOD BC
V0B 2G0

MR RAY CHOPIUK
COAL MINING RESEARCH CENTRE
202 11111 87 AVE
EDMONTON ALTA
T6G 0X9

MR BRIAN CHURCHILL
FISH & WILDLIFE BR
MIN OF ENVIRONMENT
9711 100 AVE
FORT ST JOHN BC
V1J 1Y2

MR TOM CLARK
MARKETING ACCOUNT EXECUTIVE
WEYERHAEUSER CO
BOX 1465
TACOMA WASH USA 98477

MR L COLE
TECHMAN ENGINEERING LTD
926 5 AVE SW
CALGARY ALTA
T2P 2M7

MR D C COOK
CASSIAR RESOURCES
DIV OF BRINCO MINING
CASSIAR BC
V0C 1E0

MR EDWIN COOK
GULF MINERALS CANADA LTD
BOX 2070
SASKATOON SASK
S7K 3S7

MR RON COOPER
FLATHEAD BASIN ENVIR STUDY
723 5 AVE
KALISPELL MONT USA
79901

MR RICHARD COWAN
NORTHERN PIPELINE AGENCY
400 4 AVE SW
CALGARY ALTA
T2P 0J4

MR J J CRABB
CROWS NEST RESOURCES
SHELL CENTER
400 4 AVE SW
CALGARY ALTA
T2P 2M7

MR JEAN-MICHEL CREPIN
NORWEST SOIL RESEARCH LTD
6788 99 ST
EDMONTON ALTA
T6E 5B8

MR R L CROOK
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
105 525 SUPERIOR ST
VICTORIA BC
V8V 1T7

MR BRIAN CULLUM
MIN OF FORESTS
BOX 730
FERNIE BC
V0B 1M0

MR JIM CUNNINGHAM
PETRO CANADA EXPLORATION INC
BOX 2844
CALGARY ALTA
T2P 3E3

MR D L DABBS
ALSANDS PROJECT GROUP
BOX 2606 STN M
CALGARY ALTA
T2P 3A9

MR BOB DAMS
INTERA ENVIR CONSULTANTS
406 7015 MCLEOD TRAIL SW
CALGARY ALTA

MR PETER DAVIDSON
BOX 152
COLEMAN ALTA
T0K 0M0

MR JOHN B DAWSON MGR
DAWSON SEED CO
BOX 91204
WEST BANCOUVER BC
V7V 3N6

MR P M DEAN
ENVIRONMENTAL COORDINATOR
CYPRUS ANVIL MINING CORP
330 355 BURRARD ST
VANCOUVER BC
V6C 2G8

MR CHARLES DEANGELIS
GRASS GROWERS INC
424 COTTAGE PL
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V2L 3H9

MR D FOURT
FORESTRY COMM RESEARCH STN
ALICE HOLT LODGE
WREICLESHAM
FARHAM SURREY
ENGLAND

DR A FREYMAN
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
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VANCOUVER BC
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E KOOTENAY COMM COLLEGE
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PETROLEUM RESOURCES
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FORT ST JOHN BC
V1J 4M9

MR J HANSEN
2004 5 ST SW
CALGARY ALTA
T25 2B4

DR JEFFREY HARVEY
810 WEST
BOX 1498
KALLISPELL MT USA 59901

MR F G HATHORN
B C HYDRO & POWER AUTHORITY
2863 W 38 AVE
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DR R HAWES
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VICTORIA BC
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MR B E HURDLE
KLOHN LEONOFF
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CALGARY ALTA
T2H 2L7

MR PAUL IMADO
BC HYDRO & POWER AUTHORITY
BOX 640
CACHE CREEK BC
V0K 1H0

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DENISON MINES
Box 11575
650 W GEORGIA ST
VANCOUVER BC
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98148

MR D J JONES
IEC
202 5600 CEDARBRIDGE WAY
RICHMOND BC
V6X 2A7

MR RON KEATING
R D KEATING & ASSOC
AGRICULTURAL CONSULTANTS
10 CLYDE RD
CHRISTCHURCH 4
NEW ZEALAND

MR DENNIS KERFOOT
ALLAN KENNEDY - ESSO RESOURCES
PETROCANADA
BOX 2844
CALGARY ALTA
T2P 3E3

MR R KIND
T M THOMSON & ASSOCIATES
1006 GOVERNMENT ST
VICTORIA BC
V8W 1X7

MR W KING
GREENPARK
17212 106 AVE
EDMONTON ALTA
T5S 1H9

MR D J KLYM
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FORT MCMURRAY ALTA
T9H 3E3

MR L KRYVIAK
ALBERTA GOVERNMENT

MR TED F LAIDLAW
LAIDLAW VEGETATION CONSULTING
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ELKFORD BC
V0B 1H0

MS ARLENE LANNON
CANADA CEMENT LAFARGE
606 CATHCART ST
MONTREAL QUE

MR J LANT
CROWS NEST RESOURCES
BOX 2003
SPARWOOD BC
V0B 2G0

DR L M LAVKULICH
FACULTY OF AGRIC SCIENCES
248 23357 MAIN MALL UBC
VANCOUVER BC
V6T 2A2

MR TED LEA
MIN OF ENVIRONMENT
VEGETATION UNIT
1873 SPALL RD
KELOWNA BC
V1Y 4B2

MR A G R LUKE
C/O DEPT OF APPLIED BIOLOGY
UNIV OF CAMBRIDGE
PEMBROKE ST
CAMBRIDGE ENGLAND
CB23DX

MR PHILLIP D LULMAN
RECLAMATION PLANNER
TRANS ALTA RESOURCES
BOX 1900 110 12 AVE SW
CALGARY ALTA
T2P 2M1

MR S LUNN
PAN CANADIAN PETROLEUM
BOX 2850
CALGARY ALTA
T2P 2S5

MR A MAGNUSSON
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BOX 10335
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480 1066 W HASTINGS
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V6E 3X1

MR MCAITTERICK
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CALGARY ALTA
T2E 6L7

MR GIB MCARTHUR
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
PARLIAMENT BUILDINGS
VICTORIA BC
V8V 1X4

DR DOUG MCBRIDE
SELKIRK COLLEGE
BOX 1200
CASTLEGAR BC
V1N 3J1

HON R H MCCLELLAND
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
PARLIAMENT BUILDINGS
VICTORIA BC
V8V 1X4

MR J MCCUE
NEWMONT MINES LTD
BOX 520
PRINCETON BC
V0X 1W0

MR J D MCDONALD
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
105 525 SUPERIOR ST
VICTORIA BC
V8V 1T7

MR LOUISE MCHEAUD
GULF CANADA RESOURCES INC
BOX 130
CALGARY ALTA
T2P 2R9

MR BRIAN MCLAUGHLIN
DEPT OF BIOLOGY
QUEENS UNIVERSITY
KINGSTON ONT
K7L 3N6

MR DOUGLAS MEAD
SHELL CANADA RES
BOX 100
CALGARY, ALTA

MR BLAKE MEDLAR
WATER MANAGEMENT BR
MIN OF ENVIRONMENT
1011 4 AVE
PRINCE GEORGE BC
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MR GENE MICHELSON
BC COAL
BOX 2000
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BC COAL
BOX 2000
SPARWOOD BC
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MS ANNE MOODY
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MR BILL MORRELL
CROWS NEST RES
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SPARWOOD BC
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MRS D MORRIS
WESTCOAST TRANSMISSION
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MR KEN MOWICKA
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BC RESEARCH
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MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
105 525 SUPERIOR ST
VICTORIA BC
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MR DIEGO ROMERO
WABUSH MINES
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WABUSH NFLD

MR M J ROWELL
NORWEST SOIL RESEARCH INC
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LANGLEY BC
V3A 5E8

MR H G RUSHTON
CROWS NEST RESOURCES
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CALGARY ALTA
T2P 2M7

MR D RYDER
BC COAL
BOX 2000
SPARWOOD BC
V0B 2G0

MR E SADAR
MINISTRY OF ENERGY MINES &
PETROLEUM RESOURCES
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KAMLOOPS BC
V2B 7W8

MR P SAHLSTROM
TERRASOL REVEGETATION EROSION
BOX 2092
VANCOUVER BC
V6B 3T2

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BC HYDRO & POWER AUTHORITY
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MR HARVEY SASAKI
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200 RANGE RD
WHITEHORSE YUKON
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NELSON BC

MR W SCHAFER
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98422

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VANCOUVER BC
V6E 3J7

MR A SCHUMACHER
C/0 MR PHIL BURTON
MONENCO
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T2G 0P6

MR STEVEN SCHUSTER
OREGON DEPT OF GEO & MINING
INDUSTRY
1129 SE SANTAIN
ALBANY ORE USA 97321

MR J SEDLACEK
PETRO CANADA
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CALGARY ALTA
T2P 3E3

MR ROGER SHIELDS
DENISON MINES LTD
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650 W GEORGIA ST
VANCOUVER BC
V6B 4N7

MR H P SIMS
ALBERTA ENV
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T5K 2J6

MR G SINGLETON
HARDY ASSOCIATES
4052 GRAVELEY ST
BURNABY BC
V5C 3T6

MS JILL M SINGLETON
5959 STUDENT UNION MALL
BOX 1022
UBC
VANCOUVER BC
V6T 1K2

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MR BRUCE SKIRROW
MCINTYRE MINES LTD
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PETROLEUM RESOURCES
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KAMLOOPS BC
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MR JOHN SOURS
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POST FALLS ID USA
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MR RAY SPEER
TECLMAN ENGINEERING
926 5 AVE SW
BOX 2840
CALGARY ALTA
T2P 2M7

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MR NIGEL STONESTREET
MR WADE STOGRAN IEC
BC COAL
BOX 2000
SPARWOOD BC
V0B 2G0

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5916 BOW-WATER CRES NW
CALGARY ALTA
T3B 2E4

MR GRANT SUTHERLAND
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KITSAULT BC
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MR SAMUEL K TAKYI
ALBERTA FOREST SERVICE
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9915 108 ST
EDMONTON ALTA
T5K 2C9

DR J THIRGOOD
FACULTY OF FORESTRY
UNIV OF BC
VANCOUVER BC

MS CAROL THOMPSON
VEGETATION TECHNICIAN
MIN OF ENVIRONMENT
1873 SPALL RD
KELOWNA BC
V1Y 4B2

MR HERBERT TOMM
MR CRAIG TOMLINSON
- HIGHMONT
31 CAMPBELL DR
STONY PLAIN ALTA
T0E 2G0

MR DON TOWNSEND
CROWS NEST RES
BOX 2003
SPARWOOD BC
V0B 2G0

MR S J TRUSCOTT
MIN OF ENV ASSESSMENT BR
PARLIAMENT BLDGS
VICTORIA BC
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MR PETER WARD
SCHULTZ INTERNATIONAL LTD
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VANCOUVER BC
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MR STEVE WARNER
ASSISTANT ENV PLANNER
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MS LIND WATSON
TECHMAN ENGINEERING LTD
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CALGARY ALTA
T2P 2M7

MR GLEN WATTS
FISH & WILDLIFE BR
MIN OF ENV
9711 100 AVE
FORT ST JOHN BC
V1J 1Y2

MS NANCY WEEDLE
PETRO CANADA
BOX 2844
CALGARY ALTA
T2P 3E3

MR B WEENK
GIBRALTAR MINES LTD
BOX 130
MCLEESE LAKE BC
V0L 1P0

DR WEIJER
UNIV OF ALBERTA
BOX 3015
EDMONTON ALTA

MR ROBERT WHEELER
JACKLYN SEED CO
W 5300 JACKLYN AVE
POST FALLS ID USA
83854

MR BRIAN WILKES
MIN OF LANDS PARKS & HOUSING
BOX 3460
3793 ALFRED AVE
SMITHERS BC
V0J 2N0

MR J E WINCH
CDN LAND RECLAMATION ASSOC
BOX 682
GUELPH ONT
N1G 6L3

MR BRUCE WINDRUM
CELLOFIBRE INDUSTRIES
8804 53 AVE
EDMONTON ALTA
T6E 5G2

MS MARCIA HAMANN WOLFE
KAISER STEEL CORP
BOX 1107
RATON NM USA 87740

MR BARRY WOOD
MIN OF ENVIRONMENT
310 WARD ST
NELSON BC
V1L 5S4

MR P ZIEMKIEWICZ
ENERGY & NATURAL RES
PETROLEUM PLAZA S TOWER
9915 108 ST
EDMONTON ALTA
T5K 2C9

MR RICHARD ZROBACK
TECHMAN ENGINEERING LTD
BOX 2840
CALGARY ALTA
T2P 2M7

MR KAL ZURKAN
LORNEX MINES
BOX 1500
LOGAN LAKE BC
V0K 1W0

STUDENT PARTICIPANTS

Dainteith, Nola	B.C. Coal
Davis, Gerry	Ministry of Forests (Nelson)
Fitzpatrice, Joe	Ministry of Forests (Nelson)
Fraser, Dave	B.C. Coal
Gibson, Carleen	B.C. Coal
Howard, Chris	B.C. Coal
Huiberts, Joan	Ministry of Forests (Nelson)
Larson, Joanne	B.C. Coal
Lawrence, Joanne	B.C. Coal
Lloyd, Jiggy	Ministry of Energy, Mines & Petroleum Resources
Martin, Dale	Ministry of Forests (Nelson)
McCallum, Martha	University of Calgary
McCleanen, Rod	B.C. Coal
Oakley, D.	Kimberley, B.C.
Rouse, Clayton	B.C. Coal
Sasasivaiah, R.S.	University of Alberta
Simmerling, Harold	B.C. Coal
Smythe, Clint	Ministry of Energy, Mines & Petroleum Resources

Province of British Columbia

Ministry of
Energy, Mines and
Petroleum Resources