REPORT #
RRTAC 90-8

PLAINS HYDROLOGY AND

RECLAMATION PROJECT:

SUMMARY REPORT

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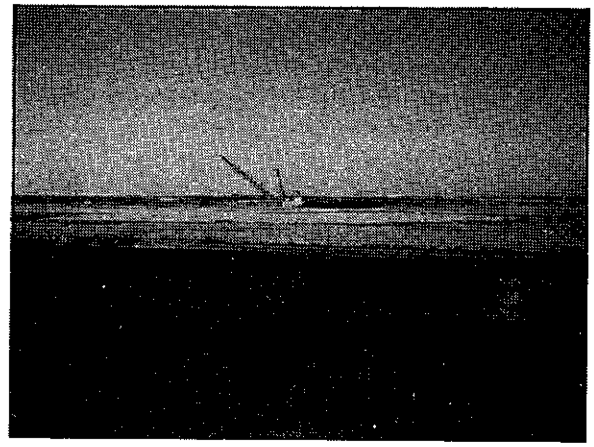
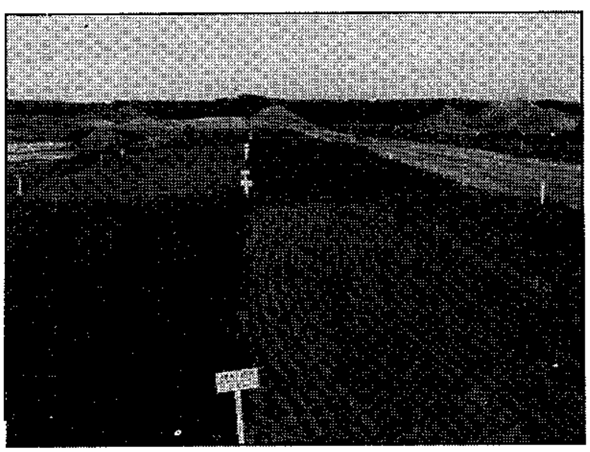


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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

REVIEWS

This report has been reviewed by members of the Reclamation Research Technical Advisory Committee and the Plains Coal Reclamation Research Program Committee.

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EXECUTIVE SUMMARY

Between 1979 and 1988, the Plains Hydrology and Reclamation Project (PHRP) investigated interactions of groundwater, soils, and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The overall goal of PHRP was: (1) to predict the long-term success and the hydrologic impacts of current reclamation practices; and (2) to develop reclamation technology that will allow modification of current practice to assure long-term success and mitigate deleterious environmental consequences.

The first phase of the study, which was completed in 1984, included characterization and instrumentation of two study areas: the Battle River study area, which included Diplomat, Vesta and Paintearth Mines, and the Lake Wabamun study area, which included the Highvale and Whitewood Mines. In the Battle River mining area, the study sites at both Diplomat and Vesta Mines were situated in areas that were mined during the transition from small-scale surface mining to modern, larger scale mining practices. At both mines initial instrumentation, which was installed in 1979 and 1980, was situated in areas of older mining that were reclaimed to pre-modern standards. Later instrumentation, which was installed between 1985 and 1987, was situated in newly reclaimed areas that had been mined using current practice. Paintearth Mine was opened in the early 1980's and all instrumentation was installed in newly reclaimed sites. In the Lake Wabamun mining area, the instrumented areas at both Highvale and Whitewood Mines were located in pits that had been mined during the early to mid-1970's using modern mining and reclamation practices. Active mining continued in other pits of these mines throughout the project.

Research from the first phase of study led to the focusing on three problem areas in the second phase of the project : (1) the potential salinization of reconstructed soils from shallow groundwater; (2) the potential deterioration of capability for agriculture as a result of differential subsidence; and (3) the potential changes in the

chemical and physical characteristics of reconstructed soils. This report summarizes the results of both phases of PHRP. It brings the project's findings together in one coherent document, and as such exhibits the rationale behind a holistic approach to reclamation research. For a more in-depth treatment of any particular topic, the reader is directed to the project's extensive technical reports and publications (Appendix 1).

Mining and reclamation of coal in the plains of Alberta affect two important resources: groundwater resources and agricultural resources (soil and landscape). The most important hydrological impact of surface mining of coal in the plains of Alberta is the reduction in groundwater supply capability within mined areas. Groundwater supplies in areas of potential surface mining of coal are derived almost entirely from either fractured coal beds or sandstone overlying the coal. Surface mining removes these aquifers and replaces them with mine spoil, whose properties, in general, preclude its development as a water supply. The agricultural resources disrupted by mining are replaced by a reconstructed landscape that is not initially in a state of either physical or chemical equilibrium. Depending on reclamation practices, evolution of the reconstructed landscape may result in an agricultural resource that may be better, as good as, or potentially degraded with respect to the pre-mining resource.

GROUNDWATER RESOURCES

The hydraulic properties of mine spoil in the plains of Alberta preclude development of water supplies above the base of disturbance within reclaimed mine sites. Cast overburden spoil has values of hydraulic conductivity that are considerably lower than those of the pre-mining coal aquifers, in the range of 10^{-7} to 10^{-9} m/s. At these values of hydraulic conductivity, the spoil is not capable of supplying water to wells. In addition, the major ion chemistry of groundwater in mine spoil was found to be considerably degraded relative to pre-mining aquifers. Mean Total Dissolved Solids values are generally 5000 to 7000 mg/L, and the water is generally saturated with respect to calcite, dolomite, and gypsum. At these concentrations, the water is unfit for consumption by both humans and livestock. The brackish nature of groundwater in mine spoil appears to be an inevitable consequence of mining in the plains region of Alberta.

There is no known method of materials handling that would alter either the hydraulic conductivity of mine spoil or the chemical make up of the groundwater in mine spoil in this region. We conclude that disruption of shallow groundwater supplies within and above the coal is an unavoidable result of mining in the plains region. The only exception to this generalization would be where extensive, thick sand or gravel deposits lie on the bedrock surface or within the unconsolidated drift overburden. As indicated by Trudell and Moran (1986), it might be possible in such an instance to reconstruct a zone with significantly higher hydraulic conductivity by selectively handling and placing this sand or gravel. There is limited potential to replace the shallow groundwater supplies that are disturbed by mining. Deeper coal or sandstone aquifers that are capable of replacing the shallow coal aquifers removed by mining are present only in some areas. In places where the water quality in these aquifers is acceptable for human consumption, these aquifers offer the best option to replace water supplies lost as a result of mining.

AGRICULTURAL RESOURCES

The impacts of mining on agricultural resources occur in two time frames: (1) immediate effects, and (2) progressive effects that have long-term implications. Immediate effects focus on the product of the soil reconstruction process. Materials handling associated with mining results in the mixing of the pre-existing soils to produce a reconstructed soil mantle of uniform thickness with properties that are an average of the pre-mining soils. Present requirements for the replacement of up to 1.5 m of subsoil material in addition to topsoil above sodic spoil appear to assure immediate post-reclamation capability that is comparable to that prior to mining. There is no evidence to suggest that replacement of greater thicknesses of buffer material would further improve capability.

Progressive effects focus on limitations and improvements to agriculture that develop over time; specifically, differential subsidence, which leads to ponding, soil salinization in lowland settings, and leaching in upland settings. Differential subsidence forms depressions that are aligned between the original spoil ridges, and appears to be an unavoidable consequence of dragline mining (Dusseault et al. 1985). These depressions, which typically occupy from five to ten percent of the reclaimed surface, increase infiltration and accelerate differential subsidence by ponding water during spring melt and heavy summer rain storms. As a result, cultivation patterns are disrupted, seeding and/or crop growth is restricted within the ponded depressions, and salinization may occur in the fringe area around the depression.

Salinization is a natural phenomenon whose conditions for formation are met in lowland reclaimed settings where ponding occurs, particularly if there is also ponding in the adjacent upland. Ponds in the lowland area cause the water table to persist near the surface. Where there is sufficient ponding in the upland to maintain the water table at levels above that in the adjacent lowland, groundwater will flow toward the lowland. In this setting, the fringe area around ponds in the lowland will become salinized. The flatter the landscape in the lowland, the larger the salinized area will be.

The impact of the negative progressive effects of mining and reclamation on agricultural resources can be minimized through modifications of materials placement and grading within existing operations. Grading as much of the upland portion of the reclaimed landscape as feasible into open slopes with integrated drainage can minimize ponding. Pauls et al. (in prep) report that slopes in the range of 1.5 to 3 percent along the long axis of subsidence depressions are sufficient to drain about 90 percent of the water that is ponded on existing reclaimed surfaces. Within the lowland areas, the extent of salinization can be minimized by grading to an undulating to rolling landscape with slopes of 3 percent to 5 percent. This will result in narrower zones around the lowland ponds where the water table is within the critical depth of the surface than when the terrain is more nearly level.

There is no known method to prevent the formation of lowland areas where overburden is thinner than the threshold value, other than the expensive process of transporting material from other areas in the mine. These lowland areas can be managed as productive hayland, pasture, or wildlife habitat, which adds much needed variety to the reclaimed landscape. In some cases, it may be desirable to design drainage measures into the materials handling system to facilitate management of the future lowland area.

ACKNOWLEDGEMENTS

This project was sponsored by the Reclamation Research Technical Advisory Committee (RRTAC) of the Alberta Land Conservation and Reclamation Council, with financial support from the Alberta Heritage Savings Trust Fund. Alberta Power Ltd., Luscar Ltd. – Forestburg Colleries Ltd., Manalta Coal Ltd., TransAlta Utilities Corporation, and local land owners, aided the study by providing access to lands and/or available data for the research work. The guidance and support of the various RRTAC subcommittees involved with this project is also acknowledged.

A project such as PHRP involves, and would have been impossible without, teamwork. In the course of the project's life (eight+ years), a considerable number of people with a wide variety of skills were involved in the PHRP team. At one time or another the project team included (in addition to the authors): Rod Ayrchuk, Andy Bosman, Ed Bulger, Kent Cantrell, Carol Chevalier, Robert Clarkson, Robert Faught, Robert Green, Al Howard, Michael Huemmert, Gordon Jean, Richard Li, Adrian MacLean, Steve Maltby, Anna Maslowski Schutze, Robert Miller, Brian Monroe, Tom Morris, Burt Murphy, Faye Nikiforuk, Dave Pauls, Margaret Pigot, Henry Range, Brenda Sawyer, Don Scafe, Greg Sterenberg, Karen Telder, Darrell Turnbull, Ed Wallick, Al Watson, Zdenek Widtman, and Paul Yeung, numerous summer students, and consultants Frank Schwartz and Al Crowe (hydrogeology), and Maurice Dusseault, Don Scott, Hal Soderberg and Greg Zinter (geotechnical engineering). Again, the project would not have been possible without everyone's unique contribution. In addition, the support staff of the Geological Survey and Terrain Sciences Departments within the Alberta Research Council, as well as the support staff within Council as a whole, specifically Lorne Bradley and the Graphic Services staff, are gratefully acknowledged for their contribution to the project.

1. INTRODUCTION

1.1 PROJECT OVERVIEW

Alberta's development of coal resources will expand in the coming decades. At the time the Plains Hydrology and Reclamation Project (PHRP) was initiated in 1979, major concerns about the environmental impacts of mining and reclamation of mined areas remained unanswered. Most of the land that is underlain by mineable coal in the plains area of the province is in agricultural production. Groundwater, which is commonly derived from coal beds, supplies nearly all the water needs of the region. PHRP was formed to investigate the interactions of groundwater, surface water, soils, and geology as they affect successful reclamation of surface coal mines in the plains of Alberta.

Up until 1979 reclamation research in Alberta and other parts of North America had concentrated largely on establishing soils and vegetation on graded overburden materials. Little work had focussed on the long-term productivity of these reclaimed landscapes or on the long-term impacts of mining on water resources. Existing research and field experience in working mines had showed that in most places, revegetation of graded, topsoil covered mine spoil is feasible. It was not clear whether salts liberated within the mine spoil would migrate into the replaced soil and degrade it or whether these salts would produce seriously degraded groundwater quality.

1.2 PROJECT OBJECTIVES

The overall goal of the project was to develop a predictive framework that would permit projection of success for reclamation and impact of mining on water resources on a long-term basis. Differences in physical and chemical properties of the pre-mining soils, overburden, and subsurface water were used as keys to project post-mining conditions.

The first phase of the project (1979-1984) had two main objectives that were further divided into a number of subobjectives.

OBJECTIVE A: To evaluate potential for reclamation of lands to be surface mined. The focus here is on features of landscape that make it productive in a broad sense not restricted to revegetation.

1. To assess and evaluate the potential for long-term degradation of reclaimed "soils" through salt buildup (including heavy metals).
2. To assess and evaluate the effectiveness of topographic modification and selective placement of materials to mitigate deleterious impacts on chemical quality of groundwater.
3. To assess the availability of water supply in or beneath cast overburden to support post-mining land use. Includes both quantity and quality considerations.
4. To evaluate productivity, potential capability of post-mining landscapes, and the significance of changes in productivity as a result of mining.
5. To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

OBJECTIVE B: To evaluate the long-term impact of mining and reclamation on water quantity and quality.

1. To assess and evaluate the long-term deterioration of groundwater quality in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.
2. To assess and evaluate infiltration, groundwater recharge, and groundwater-surface water interactions within cast overburden.
3. To characterize the groundwater chemistry generated within cast overburden.

Although considerable progress was made in meeting these objectives during the first five years of study, a number of issues remained unresolved. The three objectives of the second phase of the project focussed on the unresolved issues: the first was concerned with design and construction of a landscape that minimized salt buildup, the second with agricultural productivity of reclaimed lands, and the third with hydrologic implications of the reclamation process.

OBJECTIVE 1: To develop techniques and procedures that will lead to "landscape-design reclamation" to optimize long-term agricultural productivity of post-mining landscapes.

a. To define the "critical depth to water table" necessary to prevent upward salt transport as a function of type of material.
b. To describe the controls on post-mining water table position imposed by critical slope parameters (length, angle, shape) and material parameters such as hydraulic conductivity.
c. To describe the controls by slope geometry and material parameters on erosion and sediment yield in reclaimed landscapes.
d. To develop techniques and procedures to minimize disruption of designed landscapes by differential subsidence in the post-reclamation landscape.

OBJECTIVE 2: To complete development and evaluation of a capability rating system for agricultural land use of reclaimed sites by assessing productivity of reclaimed landscapes relative to similarly managed unmined sites and assessing changes in productivity over time.

OBJECTIVE 3: To complete evaluation of impacts of reclamation practices on chemical quality of groundwater in and adjacent to reclaimed mine sites.

a. To verify and generalize the model for prediction of post-reclamation groundwater chemistry that was developed as part of PHRP Phase I.

b. To determine the factors controlling the migration of groundwater of degraded chemical quality from mine spoil into adjacent unmined aquifers.

c. To evaluate groundwater recharge and stable, steady-state water-table position in mine spoil.

1.3 STUDY DESIGN

The approach used to address the project objectives was initially highly descriptive. Once the physical characteristics of the study areas were thoroughly described, more detailed studies were initiated to develop an understanding of the physical and chemical processes responsible for the important characteristics of the study areas. The initial investigation involved a study area in east central Alberta, the Battle River mining area (Figure 1). To determine the degree to which the results of the project could be generalized throughout the plains region of the province, a second study area in a different geologic and climatic setting, the Lake Wabamun mining area, was investigated (Figure 1).

The initial step in the project involved characterization of the study area in terms of climate, surface-water hydrology, geology, hydrogeology, and soils of both unmined and reclaimed landscapes. A program of testhole drilling, coring, sampling and laboratory testing was carried out to characterize the geology of the study area and to determine the chemical and mineralogical properties of the overburden. Hydrogeological instrumentation consisting of nested piezometers was installed as part of the drilling program at each testhole site. A program of testing and monitoring was conducted to determine the hydraulic properties of the various geologic units and the hydraulic head distribution in the groundwater. Samples were collected from wells and analyzed to determine the chemical and isotopic composition of the groundwater. The soils of the study area were mapped at a scale of 1:10 000. The physical, chemical and hydrological

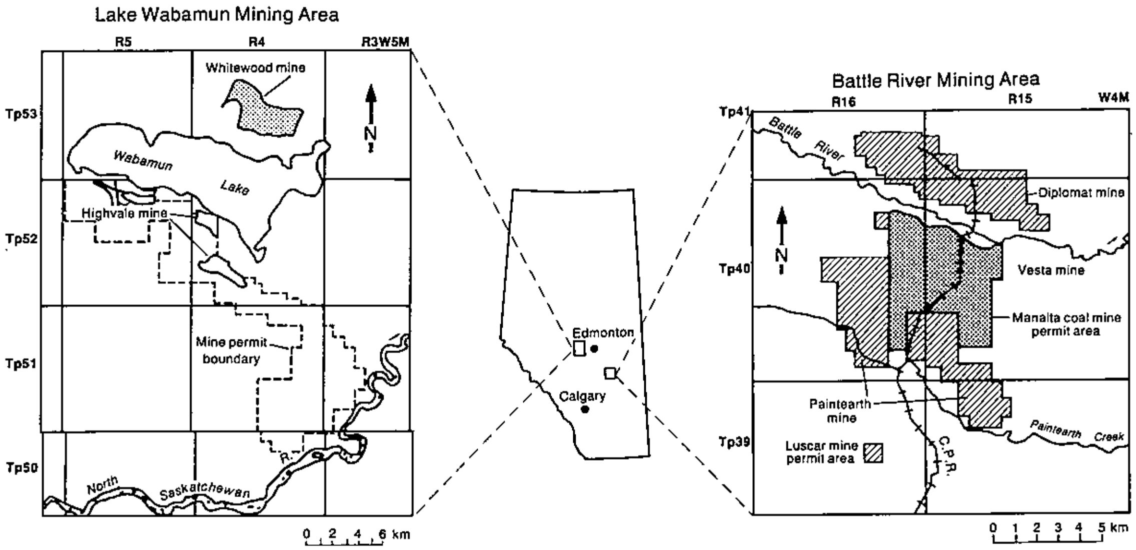

Figure 1. Map showing location of the Battle River and Lake Wabamun study areas.

properties of the important soil units were determined through programs of monitoring, sampling and laboratory testing. Following completion of the characterization phase, activities focussed on more detailed study of selected sites within the area. Detailed studies were conducted to identify, describe, and model the processes involved in the following phenomena:

1. the contribution of non-ponded settings to infiltration and groundwater recharge in both undisturbed and reconstructed landscapes;
2. the contribution of ephemerally ponded upland depressions to infiltration and groundwater recharge in reclaimed landscapes;
3. the dynamics of water movement into and out of ponds in lowland reclaimed settings;
4. changes in spoil groundwater chemistry over time;
5. the rates and directions of water and salt movement within reconstructed soils;
6. the relative roles played by vertical and lateral subsurface flow in redistributing salt in slopes adjacent to ponds in reclaimed landscapes;

7. critical water-table depth governing salt accumulation in reclaimed landscapes;
8. the rates of movement and accumulation of salt adjacent to ponded depressions in lowland reclaimed settings;
9. the changes in density of reconstructed soils over time; and
10. the spatial and temporal distribution of differential subsidence in reclaimed landscapes.

1.4 PROJECT RESULTS AND CONCLUSIONS

The results of specific components of this project are presented in a series of 22 papers published in conference proceedings and in refereed journals, as well as 18 reports published by the Reclamation Research Technical Advisory Committee (RRTAC) [Appendix 1].

This report summarizes and generalizes these results and conclusions within a framework designed to give the reader a coherent overview of the state of knowledge regarding the potential for successful reclamation and the hydrological impacts of surface mining in the plains of Alberta. Numerous references to appropriate papers or reports are included for the reader who desires a more detailed discussion of project results.

1.5 STRUCTURE OF THIS REPORT

The second section of the report is a discussion of the basis by which project results can be generalized from the study areas to other mine sites in the plains of Alberta. The third section provides an overview of the characteristics of the two study areas. Following this is a discussion of the physical and chemical characteristics of reclaimed materials and landscapes. The fifth section of the report discusses impacts of mining and reclamation on groundwater resources and on agricultural capability of reconstructed landscapes. The final section is a brief discussion of operational and regulatory implications.

2. BASIS FOR EXTRAPOLATION OF PROJECT RESULTS

The great majority of the data base for the PHRP project was derived from detailed studies at Diplomat, Vesta, and Paintearth Mines in the Battle River mining area, and from Highvale Mine in the Lake Wabamun mining area (Figure 1). In addition, limited data have been obtained from five other mine sites or mining areas: Whitewood Mine in the Lake Wabamun mining area, Genessee Mine, the Camrose-Ryley area, and the Sheerness area (Figure 2). None-the-less, the results of our study can be generalized throughout much of southern Alberta, using a three component model. The three fundamental elements of any given site that determine the physical and chemical characteristics of the site are the geology, the landscape, and the climate.

2.1 GEOLOGY OF COAL DEPOSITS IN THE PLAINS OF ALBERTA

Geology includes all aspects of the physical, chemical, and mineralogical framework within which the coal resides and which forms the bedrock overburden above the coal. The geology of a given site forms the foundation on which the landscape is developed and the raw material for the chemical and physical processes that are driven by the climate.

Certain aspects of geology vary between or even within mine sites within the plains region. For example, the overburden at Diplomat Mine is composed almost entirely of glacial till, whereas at Vesta Mine, 1 to 3 km south across the Battle River, the overburden consists dominantly of sodic bedrock. Similarly, in Pit 02 at Highvale Mine, the overburden is dominantly fine-grained bedrock silt and clay, whereas only a few kilometres away in Pit 03 of the same mine, a significant component of the overburden consists of a thick sand unit (Maslowski Schutze 1986a). In other ways, the geology is exceedingly constant over wide areas. For example, the rocks of the Lower Horseshoe Canyon Coal Zone have the same gross mineralogy and sedimentology throughout

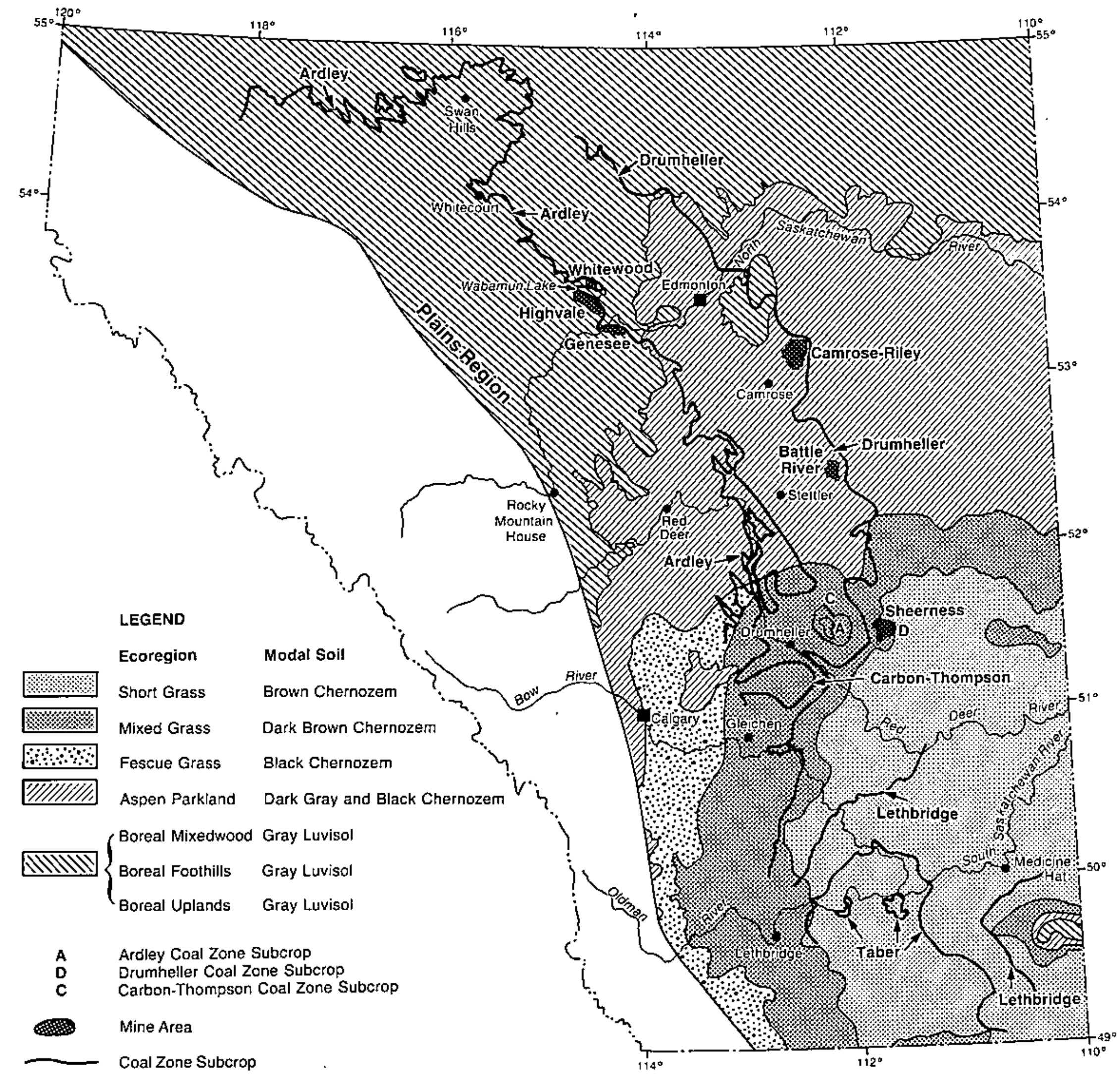

Figure 2. Map showing relationship between ecoregions and major coal zones in southern Alberta. Ecoregions are after Strong and Leggat (1981). Coal Zones are after the Energy Resources Conservation Board map Coal in Alberta.

southern Alberta reflecting their common depositional history and sediment source. The same is true of the Ardley Coal Zone at the base of the Paskapoo Formation.

Detailed studies at the Battle River mining area by Maslowski Schutze et al. (1986) and at the Camrose-Ryley area by Hughes (1984), along with a regional study by McCabe et al. (1988), are the principal sources used for lithologic and stratigraphic description of the Lower Horseshoe Canyon Coal Zone, which lies at the base of the Lower Horseshoe Canyon Formation. These studies lead to the conclusion that the depositional environment was largely marginal-marine lagoonal. The characteristics of the overburden at the Battle River mining area are taken as typical of this type of depositional setting throughout the plains region.

Detailed studies at Highvale Mine by Maslowski Schutze (1986a) and by Nikols and Lyons (1985) and the regional study by Richardson et al. (1986) are the principal sources used for lithologic and stratigraphic description of the Ardley Coal Zone in the Scollard Member of the Paskapoo Formation. These studies lead to the conclusion that the depositional environment was largely continental fluvial. The characteristics of the overburden at Highvale Mine are taken as typical of this type of depositional setting.

2.2 THE LANDSCAPE SETTING

The landscape setting controls the groundwater flow regime within a mine site at two scales. At the regional scale, which comprises features on the order of 10 km across, the landscape setting of the mine site controls the overall regional groundwater flow pattern. That is to say, the landscape setting determines, in large part, whether a site is dominated by groundwater recharge or discharge, and whether the water table lies at considerable depth or is near the surface. At this scale, for example, the Sheerness mining area is situated on a broad upland characterized by a deep water table and recharge conditions, whereas the Camrose-Ryley area is situated in a broad, generally low-relief plain characterized by a shallow water table and restricted recharge or discharge conditions. At the more detailed scale, which can be considered to address features on the order of 1 km across, or less, the near-surface geological materials and morphology are important in controlling whether a site is well or poorly drained. At this scale, the Camrose-Ryley area is undulating to gently rolling terrain underlain dominantly by fine textured glacial sediment. Drainage is generally poorly integrated and significant portions of the area are characterized by a tendency to pond water. The Battle River study area, on the other hand, is a low relief plain, dissected by the deep valleys of Paintearth Creek and the Battle River. These valleys, which serve as a drain for groundwater flow systems to a depth of 50 to 100 m, result in greater depths to water table and generally better drained conditions than at the Camrose-Ryley area.

2.3 CLIMATE IN THE PLAINS OF ALBERTA

The climate controls the nature and strength of the chemical and physical processes of weathering and mass transport that operate within the landscape. Important climatic factors include the magnitude and timing of precipitation, the temperature regime, and the interaction of temperature, wind, and precipitation that control evaporation and evapotranspiration. The net effect of the interaction of the significant climatic factors with the landscape is expressed in the soil zones or ecoregions (Figure 2). This statement implies that within a particular ecoregion, for example the Aspen Parkland Ecoregion, which corresponds roughly to the zone of Dark Brown and Black Chernozemic soils, the similarity of chemical and physical processes that result in similar zonal soils, also produce similar overburden chemistry, shallow groundwater chemistry, equilibrium surface-water regime, and overburden weathering processes. This relationship implies that results from one study site can be applied with considerable confidence elsewhere within the same ecoregion, so long as allowance is made for geology and landscape. The relationship also implies that the characteristics of the steady-state reclaimed landscape at a site should closely resemble those of the pre-mining landscape in the vicinity of the site, so long as one compares similar geological settings and local-scale (on the order of 1 km) landscape features.

2.4 CONCLUSION

To the degree that two sites possess similar geology, landscape setting, and climate they should have similar soils, overburden characteristics, and hydrology. This model provides the basis for extrapolation of PHRP results beyond the study areas and has been used within this report to provide recommendations for reclamation practice and regulation.

3. CHARACTERIZATION OF STUDY AREAS

3.1 BATTLE RIVER STUDY AREA

3.1.1 Ecological Setting

The Battle River study area is located in the Groveland Subregion of the Aspen Parkland Ecoregion (Figure 2) [Strong and Leggat 1981]. This region, which is ecologically a transition zone between boreal forest and grassland environments, is characterized by the co-existence of Dark Brown and Black Chernozemic soils and mixed aspen and grassland vegetation. Annual precipitation is about 400 mm, with about 67 percent occurring during the growing season. The summer precipitation, although heaviest in June, is approximately uniformly distributed throughout the season. Potential evapotranspiration exceeds precipitation by about 200 mm per year. Mean summer temperatures are in the range of 12.5° C to 14.5° C. Natural vegetation in the region is dominated by fescue grassland with shrub communities and aspen groves making up secondary, but significant components. About 15 percent of the region contains aspen cover, which occurs as groves and in rings along with willows around the numerous ponded depressions, or sloughs, that dot the landscape (Strong and Leggat 1981).

Soils in the Battle River study area itself are dominantly Orthic Black and Dark Brown Chernozems, Solonetzic Black, and Solonetzic soils (Macyk and Maclean 1987). Vegetation is typical of the Groveland Subregion on the poorer soils, but the majority of the better soils are farmed. The land with the highest capability for agriculture is generally farmed in crop rotations that include cereal grains and canola, with forages being grown on land with somewhat lower capability. The poorest farm land is generally kept in pasture or is uncleared parkland or bush. A significant acreage of aspen groves and willow rings has been cleared during the past 10 years. Summer precipitation is highly variable over distances of only a few kilometres, with heavy rainstorms commonly recorded on only one or two of the three or four gauges within the study area. Maximum monthly precipitation occurs in different months from year to year.

3.1.2 Geology and Overburden Characterization

The Battle River study area is underlain by rocks of the Bearpaw and Horseshoe Canyon Formations of Late Cretaceous age (Figure 3). The Bearpaw Formation, which in the study area is at least 75 m thick, consists dominantly of marine shale, but contains three persistent sandstone beds (Figure 4). The shale at the top of the Bearpaw Formation coarsens upward into a marine margin sandstone at the base of the Horseshoe Canyon Formation, the "Delta Sandstone" (Maslowski Schutze et al. 1986). The Battle River Bed, which rests on the Delta Sandstone, generally consists of two coal seams separated by a thin parting. Three coarsening-upward cycles, which grade from shale to sandstone and have an aggregate thickness of 10 m to 12 m, overlie the Battle River Bed. The "Marker Bed", a thin coal seam that ranges in thickness from 0.15 m to 0.5 m, overlies this sequence throughout the study area. The Paintearth Bed, which lies from 6 m to 10 m above the Marker Bed, consists of two to three mineable seams separated by partings (Figure 4). At the southwestern edge of the study area, as much as 40 m of interbedded fluvial sandstone, siltstone and shale of the Horseshoe Canyon Formation overlies the Paintearth Bed. The Horseshoe Canyon Formation is overlain by from 1 m to 10 m of Pleistocene glacial drift, consisting dominantly of silty till.

Chemical and mineralogical characterization was performed on 36 drift samples and 147 bedrock samples that were collected from 10 core sites in the Battle River study area to evaluate suitability of the overburden for reclamation (Maslowski Schutze 1986b). Much of the drift is of quality acceptable to use as subsoil material in landscape reconstruction, although about 25 percent of the drift samples were limited by salinity, having electrical conductivity (EC) values in excess of 4.0 dS/m, and about 35 percent had limiting sodium concentrations, having sodium adsorption ratio (SAR) values in excess of 10. All the bedrock samples were unacceptable as subsoil material as a result of sodicity limitations; no sample had SAR values less than 14.6. Two percent of the bedrock samples also had EC values in excess of 4.0 dS/m (Maslowski Schutze 1986b).

3.1.3 Hydrogeology and Groundwater Chemistry

The following discussion is extracted from a report by Trudell, Faught and Moran (1987) that describes the hydrogeology and groundwater chemistry of the Battle River study area in considerable detail.

The regional groundwater flow direction on the south side of the Battle River valley is from southwest to northeast in permeable coal beds and continuous sandstone units beneath the coal. On the north side of the Battle River valley,

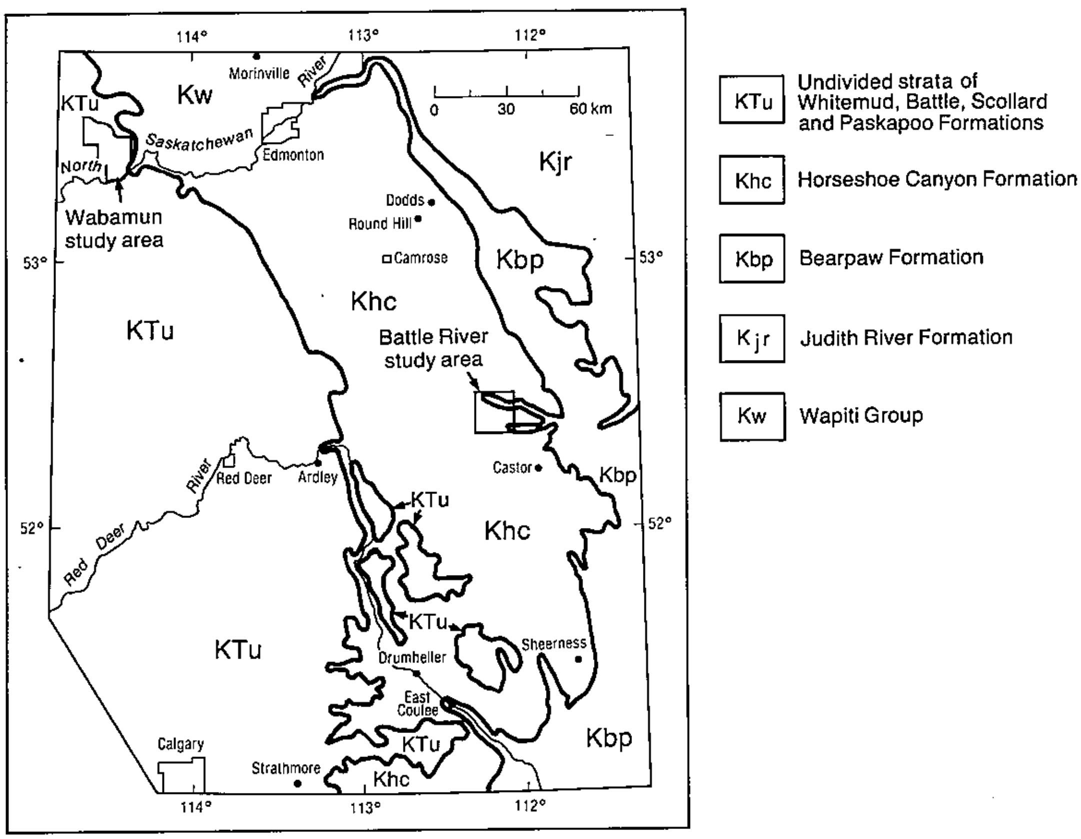

Figure 3. Map showing bedrock geology of east-central Alberta and location of Battle River and Lake Wabamun study areas (After Maslowski Schutze et al. 1986).

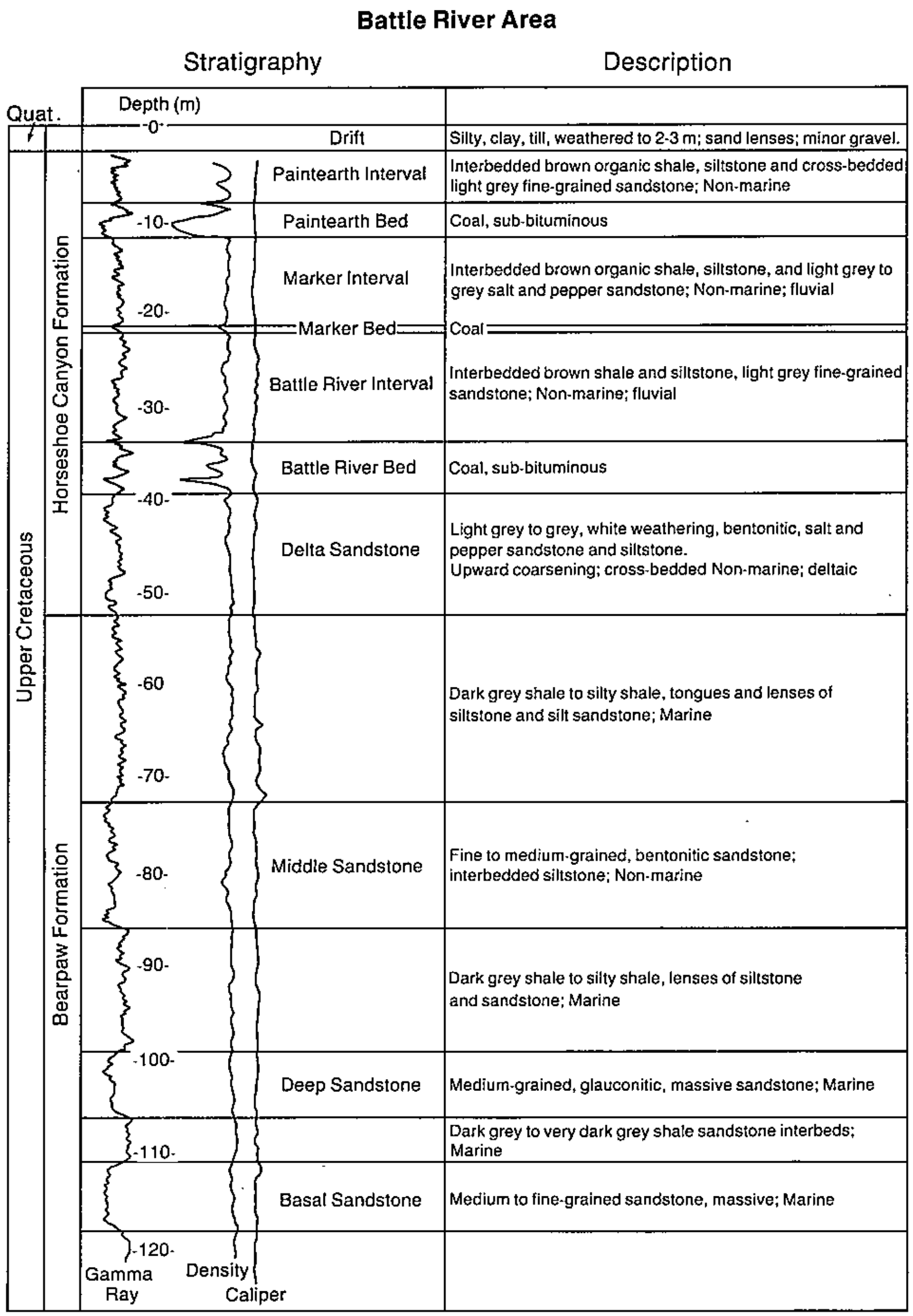

Figure 4. Generalized stratigraphic column of the Battle River study area, Lower Horseshoe Canyon Coal Zone (After Trudell et al. 1987).

groundwater flow in aquifers beneath the Battle River Bed is to the south or southwest, toward the valley of the Battle River. In the drift and in shallow bedrock units that have been dissected by post-glacial erosion, groundwater flow is more strongly controlled by topography and outcrop patterns. Within the study area, groundwater flow is vertically downward, except beneath the floor of the Battle River, where upward flow is encountered.

The chemistry of shallow groundwater in the drift and Paintearth Bed is highly variable, and in places the water is quite brackish. The chemical composition of groundwater reflects dissolution of abundant secondary salt in the soil, as well as chemical weathering in the near-surface environment. The deep bedrock groundwater is relatively brackish $Na^+ - HCO_3/Cl^-$ water that is uniform in composition. The chemical composition reflects a marine environment of deposition, and long flow path or residence time in more stagnant zones where diffusion is important. The sandstone beds in the Bearpaw Formation, particularly the Middle Sandstone and Basal Sandstone in the western and southern parts of the area, typically contain this type of water. Groundwater in bedrock at intermediate depths reflects a mixture of locally recharged, near-surface water and deeper bedrock derived water. At shallow depths below the water table, sulfate reduction begins to occur and the level of sulfate drops. Ion exchange (of dissolved calcium for adsorbed sodium) results in a decline in calcium concentrations. In zones that are isolated from the regional flow system and unaffected by strong local recharge, the groundwater is highly brackish and contains considerably more chloride than elsewhere in the same units.

In nearly all of the 40 samples that were analyzed for the nine trace elements, antimony (Sb), arsenic (As), boron (B), cadmium (Cd), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), and selenium (Se), concentrations were at levels well below the allowable concentrations for irrigation water or human consumption, or the elements were not detected.

3.2 LAKE WABAMUN STUDY AREA

3.2.1 Ecological Setting

The Lake Wabamun study area is located in the Moist Mixedwood Subregion of the Boreal Mixedwood Ecoregion (Figure 2) [Strong and Leggat 1981]. This region, which is ecologically a transition zone between mixed conifer-deciduous forest and parkland environments, is characterized by Grey Luvisolic soils with aspen and balsam poplar woodlands. Annual precipitation is about 440 mm, with more than 70 percent, occurring during the growing season. July is generally the wettest month. Potential evapotranspiration exceeds precipitation by about 200 mm per year. Mean summer temperatures are in the range of 10.5° C to 13.5° C, which is considerably cooler than the Aspen Parkland Ecoregion. Natural vegetation in the region is dominated by woodlands comprised of aspen, balsam poplar, and white spruce (Strong and Leggat 1981).

Soils in the Lake Wabamun study area are dominantly Grey Luvisols with significant areas of Solonetzic soils. The typical vegetation of the Moist Mixedwood Subregion covers significant areas, but the majority of the better soils are farmed. The land with the highest capability for agriculture is generally farmed in crop rotations that include cereal grains and canola, with forages being grown on land with somewhat lower capability. The poorest farm land is generally kept in pasture or is uncleared.

3.2.2 Geology and Overburden Characterization

In the Lake Wabamun study area, the Ardley Coal Zone, which is the top of the Scollard Member of the Paskapoo Formation, consists of six persistent coal seams, with the upper two being the thickest and most important (Figure 5). Overlying the coal zone, the Paskapoo Formation consists of a sequence of continental fluvial sediment, which has been subdivided into four stratigraphic units (Maslowski Schutze 1986a). A dark grey shale unit, unit A, which commonly contains coal stringers and bentonite beds,

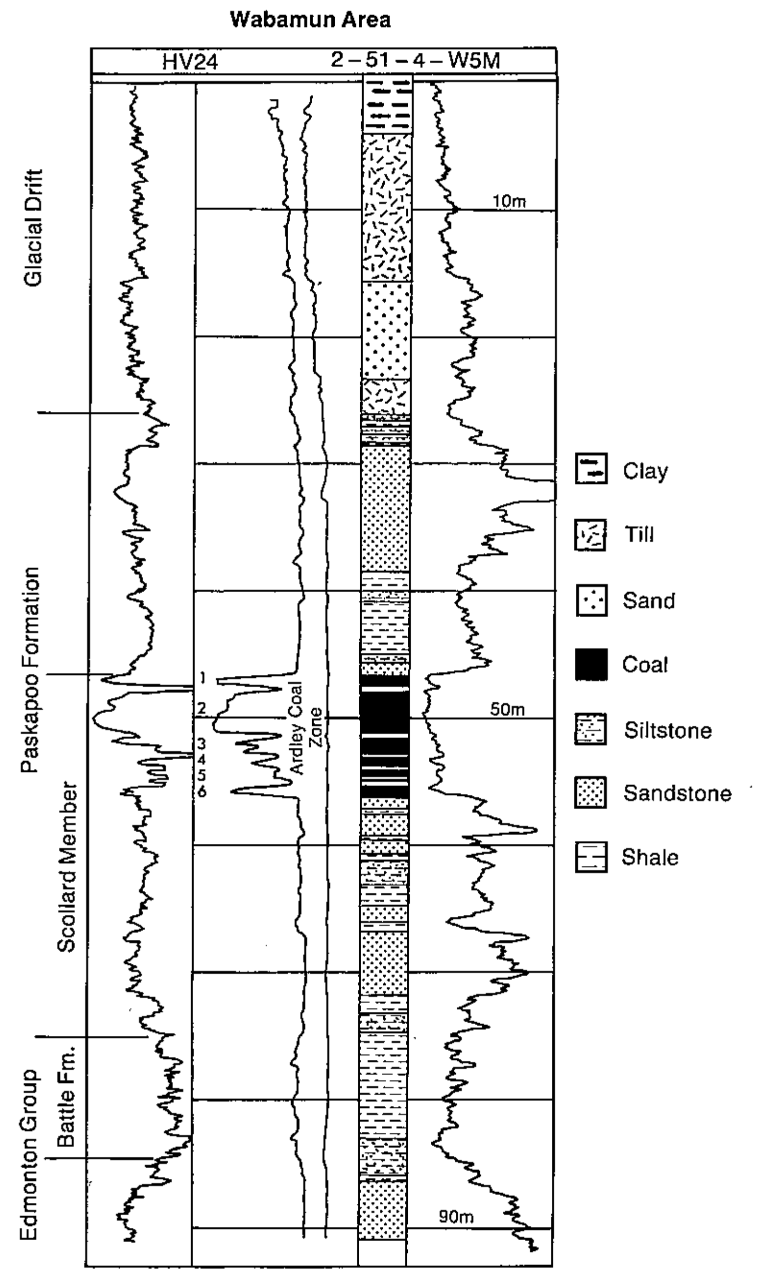

Figure 5. Generalized stratigraphic column of the Lake Wabamun study area, Ardley Coal Zone (After Maslowski Schutze 1986a).

overlies the coal. This unit is interpreted to have been deposited in ponds or lakes within the flood-basin zone of a large river valley. The overlying unit B consists of a complex sequence of thick, apparently structureless sandstone that in places grades laterally into interbedded shale, siltstone and sandstone. Unit B, which represents channel and near-channel overbank facies, comprises most of the overburden in the majority of the study area. Overlying this unit is a sequence of interbedded shale, mudstone, and minor siltstone, unit C, which represents a return to flood-basin conditions (Figure 5). Throughout the study area, the bedrock is folded, faulted, and crushed by intense glacial deformation (Fenton et al. 1986).

A variable thickness of glacial drift overlies the bedrock overburden. The drift consists of clayey to silty diamicton, which is dominantly till, clayey lake sediment, and abundant disturbed and transported blocks, lenses, and irregular masses of bedrock that were removed largely from Lake Wabamun, just to the north of Highvale Mine. The composition of the glacial drift is highly variable depending on the abundance of incorporated locally-derived bedrock material.

3.3.3 Hydrogeology and Groundwater Chemistry

The following discussion is extracted from a report by Trudell and Faught (1987) that describes the hydrogeology and groundwater chemistry of the Highvale site in considerable detail.

The thick sandstone unit overlying the Ardley Coal Zone and the coal unit itself are the major aquifers in the Highvale study area. Regional groundwater flow in these units has two principal components: (1) from the uplands in the southwestern part of the study area northward toward Lake Wabamun, and (2) from the uplands in the east-central part of the study area, southeastward toward the North Saskatchewan River.

Downward vertical hydraulic gradients over most of the area, indicate that groundwater recharge conditions dominate. Groundwater discharge conditions are present at the subcrop of the Ardley Coal Zone and overburden sandstone along the southern edge of Lake Wabamun, and around Low Water Lake. In all cases, the hydraulic head in the bedrock overburden and Ardley Coal Zone is higher than the level of Lake Wabamun. The North Saskatchewan River is the regional groundwater drain for both shallow and deep bedrock aquifers in the southern part of the study area.

The sandstone beds in the Upper Horseshoe Canyon Formation, beneath the Ardley Coal Zone, are recharged by downward seepage through the drift cover and from surface ponds in the subcrop area southeast of Lake Wabamun. Groundwater flows southward to discharge along the subcrop of the sandstone in the valley of the North Saskatchewan River.

The chemistry of groundwater in the drift is highly variable both in composition and salinity. In the shallow bedrock, groundwater is primarily of $Na^+ - HCO_3$ composition, with low to moderate salinity. Groundwater salinity reaches a maximum of 2000 to 2500 mg/L in the Ardley Coal Zone, and declines somewhat with increased depth. Groundwater in the sandstone beds in the Upper Horseshoe Canyon Formation, which are the deepest stratigraphic unit studied, at approximately 100 m depth, is also of low to moderate salinity and of $Na^+ - HCO_3$ composition.

Groundwater in all stratigraphic units is slightly undersaturated to saturated with respect to calcite and dolomite, and undersaturated with respect to gypsum. Ion exchange characteristics of all stratigraphic units except the drift indicate that dissolved calcium has been exchanged for adsorbed sodium, giving rise to sodium dominated groundwater composition.

In 65 samples, concentrations of the nine trace elements, antimony (Sb), arsenic (As), boron (B), cadmium (Cd), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), and selenium (Se), were below maximum allowable levels for irrigation water or human consumption in all cases. In addition, levels of cadmium, mercury, antimony, and selenium were below detection in almost all samples.

4. PROPERTIES OF RECLAIMED MATERIALS AND LANDSCAPES

Mining and reclamation produce changes to the natural materials and landscapes described in the previous section. New materials ("spoil") are created and the landscapes altered. This section of the report describes and characterizes the reclaimed landscape and spoil material. As part of this characterization process the surface and subsurface hydrologic regime of the reclaimed landscape are discussed.

4.1 RECLAIMED LANDSCAPES

During surface mining of coal in the plains of Alberta, the bedrock and unconsolidated sediment that comprise the overburden are removed by draglines or shovels and cast backward into the previously mined pit. As part of this process, the overburden material is broken into fragments of various sizes. This fragmentation leads to an increase in void space that in turn results in a spoil mass with a lower density than unmined overburden. Depending on the type of material involved and its initial water content, the secondary porosity created by the spaces between spoil fragments ranges from 20 to 30 percent. This "bulking" of the spoil causes the reclaimed landscape to be elevated above the surrounding unmined landscape.

Modern reclamation practice in the plains of Alberta generally involves grading spoil into long smooth surfaces that are flat or gently sloping. The topography of the reclaimed area generally reflects a smoothed version of the pre-mining topography with broad low areas where the pre-mining overburden was thinner, and locally elevated areas where overburden was thicker. Deep, steep-sided depressions are absent except as final cuts or where areas of older mining are adjacent to current mining operations.

Two types of landscape settings occur in reclaimed terrain: upland settings and lowland settings. It is important to differentiate the landscape settings, since they play different roles in the evolution of the mine spoil (i.e., hydrology, differential subsidence, soil development) and the ultimate use of the reclaimed land.

Upland settings, which constitute the majority of reclaimed areas, are generally situated above the pre-mining landscape grade and are characterized by flat to undulating terrain. Numerous small oval depressions, which are about 10 to 20 m wide by 20 to 50 m long and as much as 0.5 m deep, dot the landscape. They typically occupy from 5 to 10 percent of the reclaimed surface, which is not dissimilar to small depressions on unmined landscape. These depressions form through differential subsidence, which accompanies resaturation of the spoil (Dusseault et al. 1985). During spring melt and heavy summer rain storms these depressions capture water to produce ponds. Ponding is generally ephemeral and tends to be of limited areal extent, with the ponds perched above and not connected to the water table (Figure 6).

Lowland settings, which constitute more restricted areas within reclaimed landscapes, are generally situated at or below the pre-mining landscape grade. These settings generally occupy a greater proportion of the reclaimed landscape in older mining areas than in modern mine sites. Lowland settings develop wherever the pre-mining overburden was thin, generally less than about 4 to 5 times the thickness of the removed coal, and in the vicinity of final cuts. Lowland settings are characterized by deep depressions that result from mining operations, such as final cuts, access ramps and haul roads. Shallow, broad depressions form in areas of thinner spoil that result where the pit

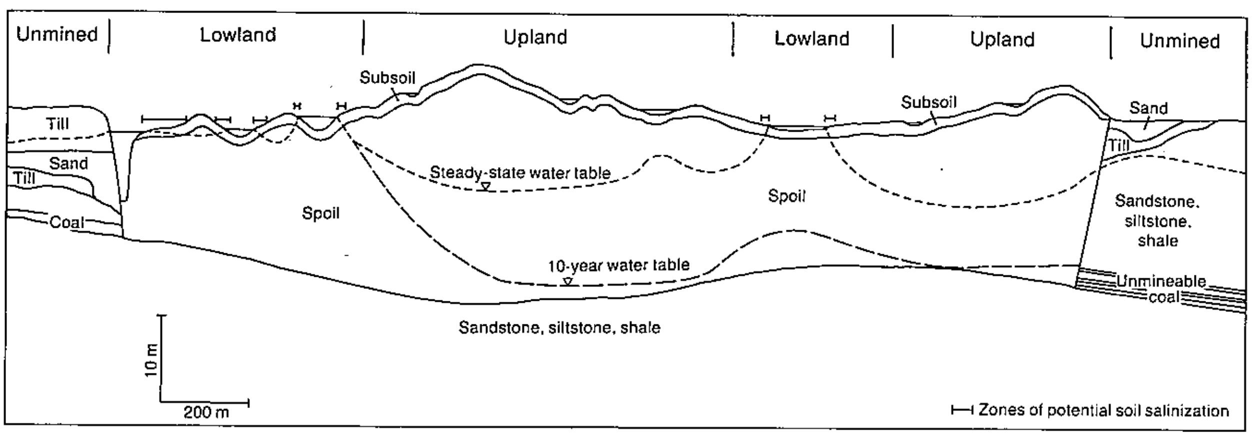

Figure 6. Schematic diagram showing landscape settings in reclaimed landscapes (After Moran et al. 1989).

orientation changed so that the overburden material was cast over an area larger than the cut from which it was excavated. In addition, small depressions form through differential subsidence. Considerable ponding of surface water occurs in lowland settings with ponds tending to be permanent or semi-permanent and connected to the water table (Figure 6).

4.2 RECONSTRUCTED SOILS

The pre-mining landscape consists of a complex mosaic of soils, which reflect differences in parent material and landscape setting. At the Battle River mining area, for example, 129 individual soil units, representing combinations of as many as five phases of 20 soil series in 12 slope classes, were mapped by Macyk and Maclean (1987). Within a limited area, where the same parent material occurs in the same topographic setting, the soil is the same and the physical and chemical properties are quite uniform. Abrupt changes in chemical and physical properties occur within short distances as one passes laterally from one soil to another. These soil units ranged from Capability Class 1, soils that have no significant limitations to agriculture, to Class 6, soils that are only capable of producing perennial forage crops (Macyk and Maclean 1987).

As part of the mining process, topsoil and subsoil are removed as discrete layers in the area to be mined and either used immediately in soil reconstruction or stockpiled for use later in the reclamation process. After mining has been completed and the spoil material graded, the soil mantle is reconstructed. Up to 1.5 m of subsoil material is placed on the spoil using scrapers. A layer of topsoil is then spread over the subsoil to a depth of 15 cm.

In the processes of removal and reconstruction, the pre-existing soil zone is mixed. Mixing results in the blurring of the abrupt distinction between different soil types that characterized the unmined landscape, resulting in a reconstructed soil mantle that is more uniform in its characteristics over larger areas than is the unmined landscape. Surface mining alters the scale over which variability in physical and chemical properties of soil occurs within the landscape. Reconstructed soils are heterogeneous on a local scale, but relatively homogeneous over larger areas (Macyk 1986). There is a greater variability in chemical and physical properties within the reconstructed soil profile and within distances of a few metres than occurs in soil profiles in the unmined landscape.

4.2.1 Density of Reconstructed Soils

Conclusions regarding density of reconstructed soils in east-central Alberta are based on data from nine unmined sites in the Battle River area and ten reclaimed sites, seven at Vesta Mine and three at Diplomat Mine. The density of reconstructed soils as compared to unmined soils varies with depth. The mean density for three reconstructed soil profiles at Diplomat Mine is greater than in comparable unmined Elnora and Heisler soil profiles to about 60 cm (Figure 7). The mean density in five reconstructed soil profiles at upland sites in Vesta Mine is greater than in comparable unmined Halkirk and Heisler soil profiles to about 45 cm (Figure 8). At Vesta Mine, the spoil below a depth of about 120 cm is appreciably less dense than parent material at unmined sites (Figure 8). The variability in density between sites is greater for reconstructed soils than for unmined soils.

4.3 HYDRAULIC CONDUCTIVITY OF MINE SPOIL

Hydraulic conductivity data are available from five different mine sites in Alberta (Figure 9, Table 1) and from adjacent unmined overburden (Figure 10, Table 2). These values were determined using two types of testing procedures, field recovery testing techniques and laboratory permeameter techniques. Hydraulic conductivity values were determined at 107 sites by single-well recovery techniques. These include 35 values from spoil at Vesta Mine, 32 from Diplomat Mine, 27 from Highvale Mine, and 13 from Whitewood Mine. An additional 90 values of hydraulic conductivity that were determined by laboratory permeameter techniques are available from spoil at Vesta (35), Diplomat (38), Highvale (10), and Paintearth (7) Mines.

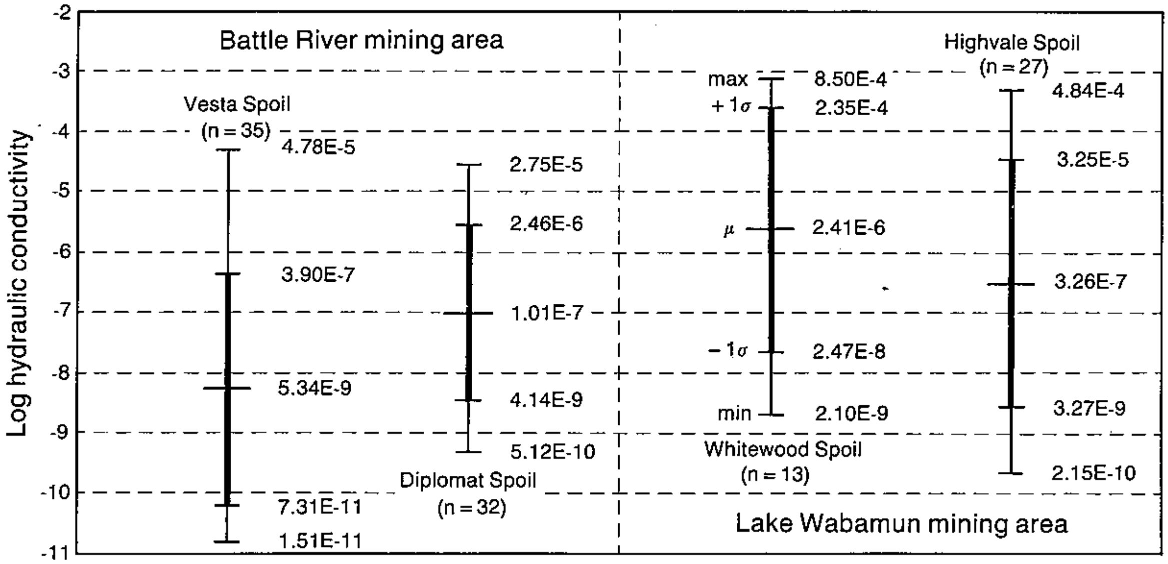

Figure 9. Distribution of hydraulic conductivity values (m/s) of mine spoil in east-central Alberta (After Moran et al. 1989).

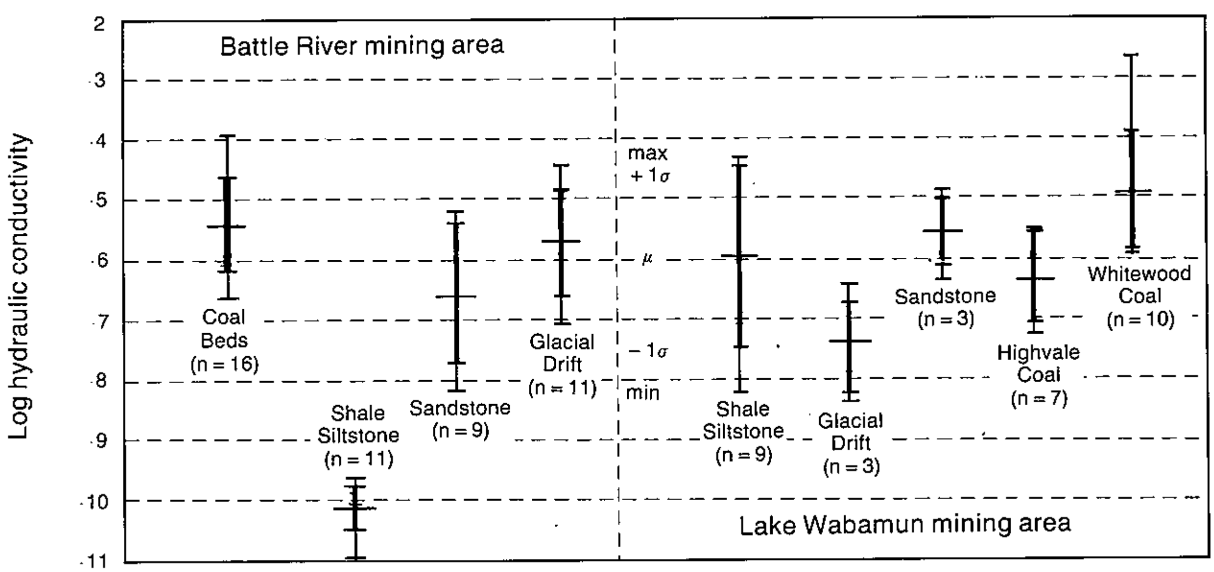

Figure 10. Distribution of hydraulic conductivity values (m/s) of coal and overburden materials in east-central Alberta.

Table 1. Summary of hydraulic conductivity data for mine spoil. Standard deviation is abbreviated SD in the column headings.

		Hydraulic Conductivity				
Mine Spoil	Number	Mean	+1 SD	-1 SD	Minimum	Maximum
Single Well Recovery						
Vesta	35	5.34E-09	3.90E-07	7.31E-11	1.51E-11	4.78E-05
Dipolmat	32	1.01E-07	2.46E-06	4.14E-09	5.12E-10	2.75E-05
Highvale	27	3.26E-07	3.25E-05	3.27E-09	2.15E-10	4.84E-04
Whitewood	13	2.41E-06	2.35E-04	2.47E-08	2.10E-09	8.50E-04
Permeameter						
Vesta	35	2.47E-11	1.54E-10	3.97E-12	3.00E-12	2.20E-08
Dipolmat	38	6.06E-11	3.97E-10	9.26E-12	4.70E-12	5.96E-08
Highvale	10	7.99E-11	6.45E-10	9.90E-12	1.35E-12	1.06E-09
Paintearth	7	6.64E-12	1.40E-11	3.16E-12	2.10E-12	1.60E-11

Table 2. Summary of hydraulic conductivity data for coal and overburden materials at the mines studied. Standard deviation is abbreviated SD in the column headings.

		Hydraulic Conductivity				
Overburden Material	Number	Mean	+1 SD	-1 SD	Minimum	Maximum
Battle River						
Drift	11	1.94E-06	1.42E-05	2.67E-07	8.05E-08	3.56E-05
Silt and Clay	11	7.33E-11	1.54E-10	3.50E-11	1.13E-11	2.25E-10
Sandstone	9	2.70E-07	3.82E-06	1.91E-08	6.18E-09	6.03E-06
Coal Beds	16	3.64E-06	2.18E-05	6.09E-07	2.15E-07	1.04E-04
Lake Wabamun						
Drift	3	4.39E-08	3.30E-07	5.83E-09	4.40E-09	1.92E-07
Shale & Siltstone	9	1.09E-06	3.41E-05	3.45E-08	5.86E-09	4.86E-05
Sandstone	8	2.74E-06	9.37E-06	8.02E-07	4.57E-07	1.30E-05
Highvale Coal	7	4.69E-07	2.56E-06	8.58E-08	5.12E-08	3.11E-06
Whitewood Coal	10	1.20E-05	1.06E-04	1.35E-06	1.30E-06	2.30E-03

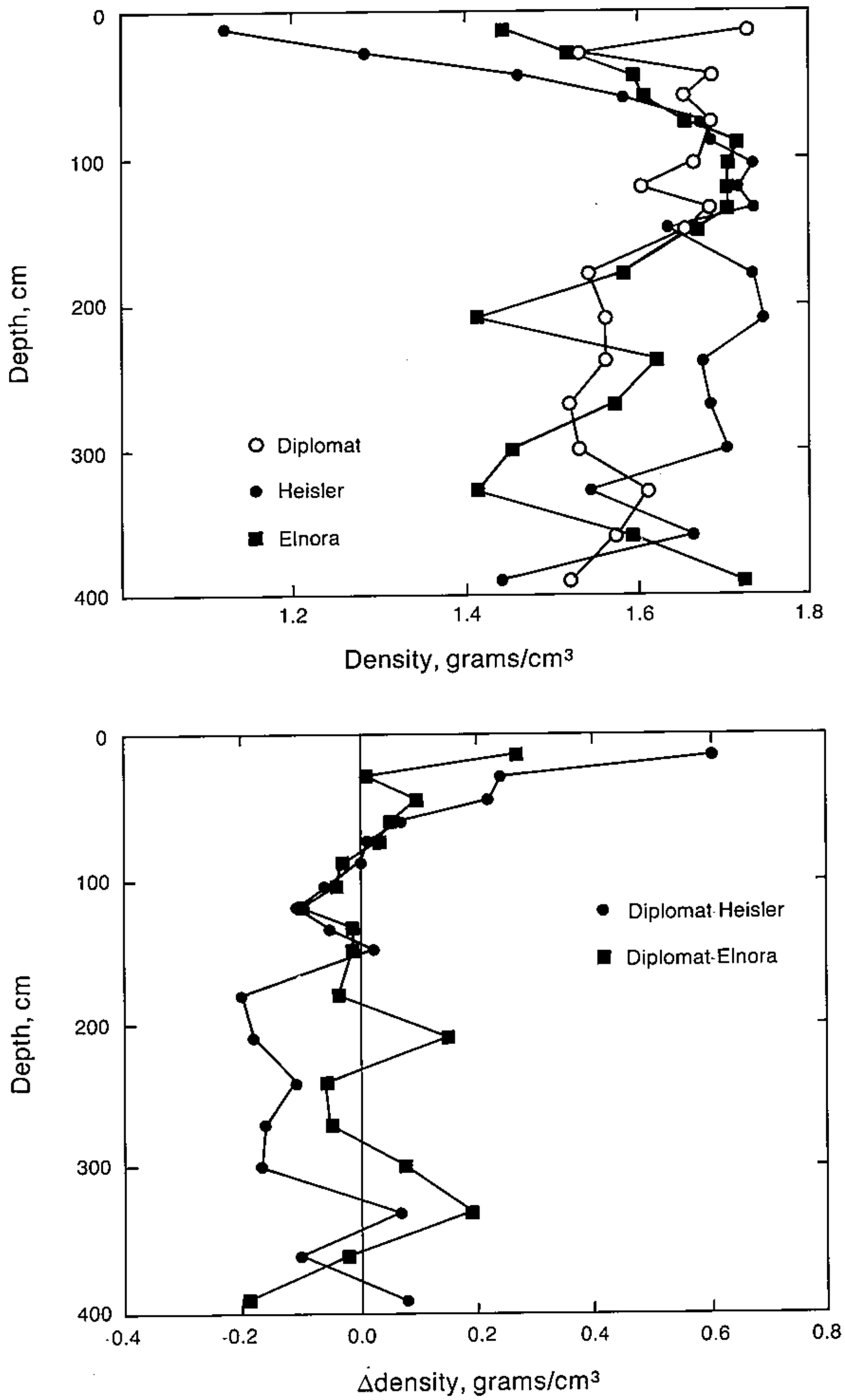

Figure 7. Density profiles for Diplomat reconstructed soil and comparable unmined Elnora and Heisler soils (upper graph). The lower graph shows the difference between the density of the reconstructed soil at Diplomat with each of the unmined soils.

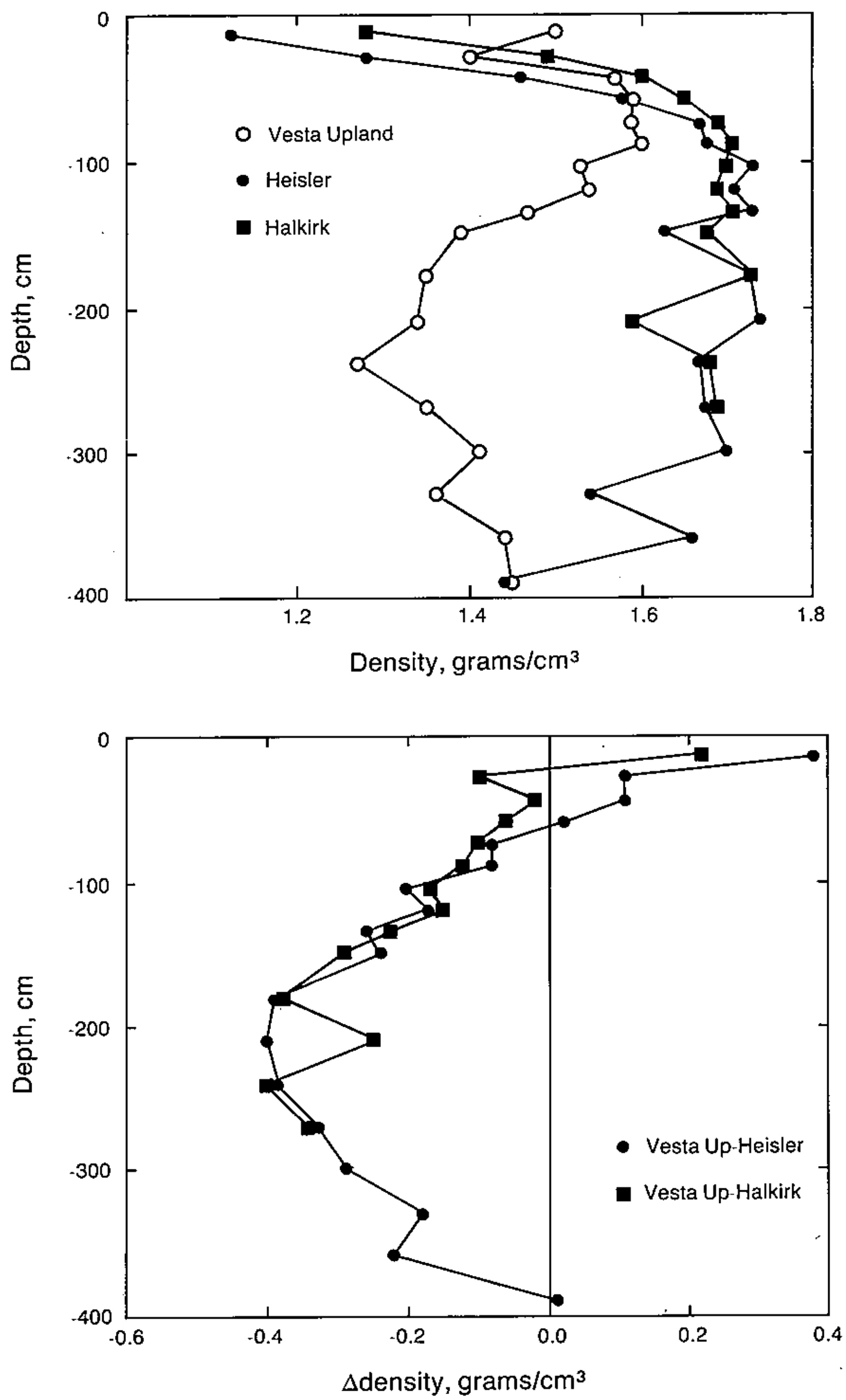

Figure 8. Density profiles for Vesta reconstructed soil and comparable unmined Halkirk and Heisler soils (upper graph). The lower graph shows the difference between the density of the reconstructed soil at Vesta with each of the unmined soils.

significantly higher hydraulic conductivity by selectively handling and placing this sand or gravel.

4.4 CHEMISTRY OF GROUNDWATER IN MINE SPOIL

The characteristics of spoil groundwater chemistry were determined by the sampling and analysis of groundwater from piezometers installed in reclaimed areas. At Vesta Mine, 43 samples were collected from 23 piezometers. At Diplomat Mine, 54 samples were collected from 32 piezometers. At Highvale Mine, 29 samples were collected from 13 piezometers installed in the reclaimed area at Pit 01. At Whitewood Mine in the Lake Wabamun mining area (Figure 1), 11 samples were also collected from piezometers installed in spoil to augment a study of that site conducted by Alberta Environment (1980).

Spoil groundwater in the Battle River mining area is primarily of the Na, Ca+Mg – SO_4, HCO_3 type (Figure 11). Mean concentration of total dissolved solids (TDS) ranges from 5875 mg/L at Diplomat Mine to 7035 mg/L at Vesta Mine. This difference in salinity reflects the difference in overburden materials at the two mines. At Diplomat Mine, the overburden material is predominantly glacial till, and approximately 20 percent of the groundwater samples are of the Ca+Mg, Na - SO_4, HCO_3 type (Figure 11). The groundwater chemistry at both mines reflects conditions of saturation with respect to gypsum, but the till-derived spoil at Diplomat Mine is characterized by a relatively low level of calcium–sodium ion exchange. At Vesta Mine where the spoil is primarily derived from bedrock of the Horseshoe Canyon Formation, a greater degree of calcium–sodium ion exchange allows more salts to dissolve before gypsum saturation is reached, giving rise to higher TDS concentrations, and a larger proportion of sodium among dissolved cations (Trudell et al. 1988).

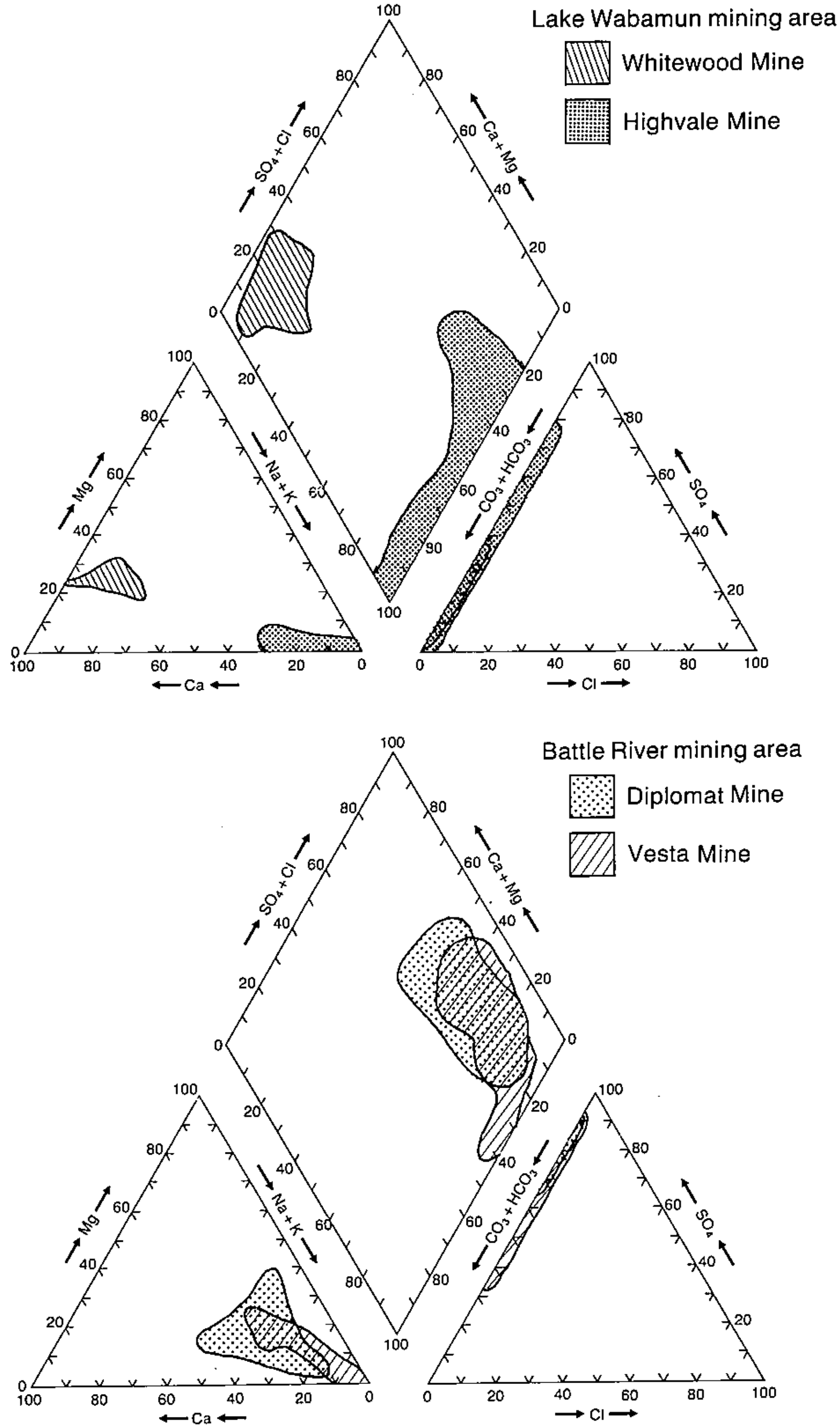

Figure 11. Piper trilinear diagram showing spoil groundwater composition at the mines studied.

Hydraulic conductivity of mine spoil is generally low, with mean values less than 3.25×10^{-7} m/s (Figure 9, Table 1). Spoil at Whitewood Mine is a notable exception, because of the sandy nature of the overburden. Hydraulic conductivity values are highly variable, ranging over as much as six orders of magnitude within individual mines (Figure 9, Table 1). Mine spoil appears to be a dual-permeability system with intergranular conductivity, as represented by permeameter tests, generally two orders of magnitude less than the bulk conductivity, as represented by single well response tests, of the spoil material (Table 1). Except for a zone of higher hydraulic conductivity that occurs at the base of the spoil in some places, and weakly developed trends of changing hydraulic conductivity with depth, variations in hydraulic conductivity are erratic and unpredictable.

Spoil derived from glacial till (e.g., Diplomat Mine) has hydraulic conductivity values that are about 1.0 to 1.5 orders of magnitude higher than those of spoil derived from bedrock (e.g., Vesta Mine) [Figure 9]. Spoil derived from overburden in the Ardley Coal Zone has hydraulic conductivity values that are from two to three orders of magnitude higher than those in the Lower Horseshoe Canyon Coal Zone (Figure 9).

Mine spoil has significantly lower hydraulic conductivity than the materials that provide water supplies for farms in the pre-mining setting, the coal beds and, to a lesser extent, sandstone beds (Table 2, Figure 10). Mine spoil is also much more variable than individual units within the pre-mining overburden. For example, sandstone beds, coal beds, and glacial drift all range in hydraulic conductivity over slightly less than three orders of magnitude; silt and clay beds in the pre-mining overburden are even less variable, ranging over slightly more than one order of magnitude (Table 2, Figure 10).

4.3.1 Discussion

The hydraulic conductivity of mine spoil was found to be low and, as is discussed in a later section, generally decreases over time. Much of this behavior is a result of the physical breakdown, by swelling and slaking of rock fragments when they come into contact with and imbibe water (Dusseault et al. 1988). Work by Dusseault and others at the University of Alberta demonstrates that this type of behavior is typical of the "transitional materials" that make up the vast majority of the Cretaceous and Tertiary bedrock elsewhere in the plains of Alberta (Dusseault et al. 1982; Dusseault et al. 1988; Dusseault and Scafe 1979; Isaac et al. 1982). The slaking and swelling behavior of this material is linked to the texture, mineralogical composition, and state of overconsolidation of these materials (Dusseault et al. 1988), which are remarkably consistent throughout the entire plains region (Locker 1963; Scott and Brooker 1968).

4.3.2 Conclusion

As a result of the fundamental properties of overburden materials in the plains of Alberta, the hydraulic conductivity of mine spoil at any future mine throughout this region will be low, at most 10^{-7} m/s. In general, the majority of mines developed in the Lower Horseshoe Canyon Coal Zone will be characterized by overburden that is dominantly fine textured bedrock. As a result, it is anticipated that mine spoil in this coal zone will have hydraulic conductivity characteristics similar to those at Vesta and Paintearth Mines, with mean values on the order of 10^{-9} m/s. In the Ardley Coal Zone it is anticipated that the majority of mines developed will have mine spoil characterized by hydraulic conductivity similar to Highvale Mine, with mean values on the order of 10^{-7} m/s. There is no known method of materials handling that would alter the hydraulic conductivity of mine spoil in the plains of Alberta.

The only exception to the generalization that spoil will have low hydraulic conductivity would occur where extensive, thick sand or gravel deposits lie on the bedrock surface or within the unconsolidated drift overburden. As indicated by Trudell and Moran (1986), it might be possible in such an instance to reconstruct a zone with

In the Lake Wabamun mining area groundwater in mine spoil from Highvale Mine is of the Na, Ca+Mg - SO_4 to Na, Ca+Mg - HCO_3 type (Figure 11), with a mean TDS of 3668 mg/L. In contrast, groundwater from mine spoil at Whitewood Mine is entirely of the Ca+Mg, Na - HCO_3 type (Figure 11), with a mean TDS of 1395 mg/L (Trudell et al. 1988). The groundwater chemistry from these two mines also reflects differences in the overburden material, which at Highvale Mine is primarily bedrock of the Paskapoo Formation, whereas at Whitewood Mine the overburden is primarily sand and gravel. Groundwater in spoil in the Battle River mining area is considerably more saline than water in the Lake Wabamun mining area. It is not known, however, whether this difference is a function of intrinsic, geologically produced differences in the overburden characteristics or results from differences in the climate in the two areas.

The groundwater in spoil at the mines studied is, in virtually all cases, more saline and has a substantially different chemical composition than the water in pre-mining aquifers (Trudell et al. 1988). Salinity increases ranged from 2.4 to 5.9 times the pre-mining levels (Figure 12). Sodium and sulfate account for the major increase in most areas, although calcium and magnesium are significantly increased in spoil of the Lower Horseshoe Canyon Coal Zone at the Battle River mining area.

Groundwater salinity has either decreased or remained essentially constant over the period from 1981 to 1987 (Figure 13). The chemistry within a plume of spoil-derived groundwater to the west of Vesta Mine (Figure 14) suggests that the initial flush of water through mine spoil had appreciably greater total dissolved solids concentration than is currently observed in the mine spoil (Trudell et al. in press).

4.4.1 <u>Discussion</u>

Two processes account for the salinity and composition of groundwater in spoil: (1) a significant amount of secondary salt that was concentrated in the lower part of the soil profile prior to mining is dissolved as the mine spoil resaturates following

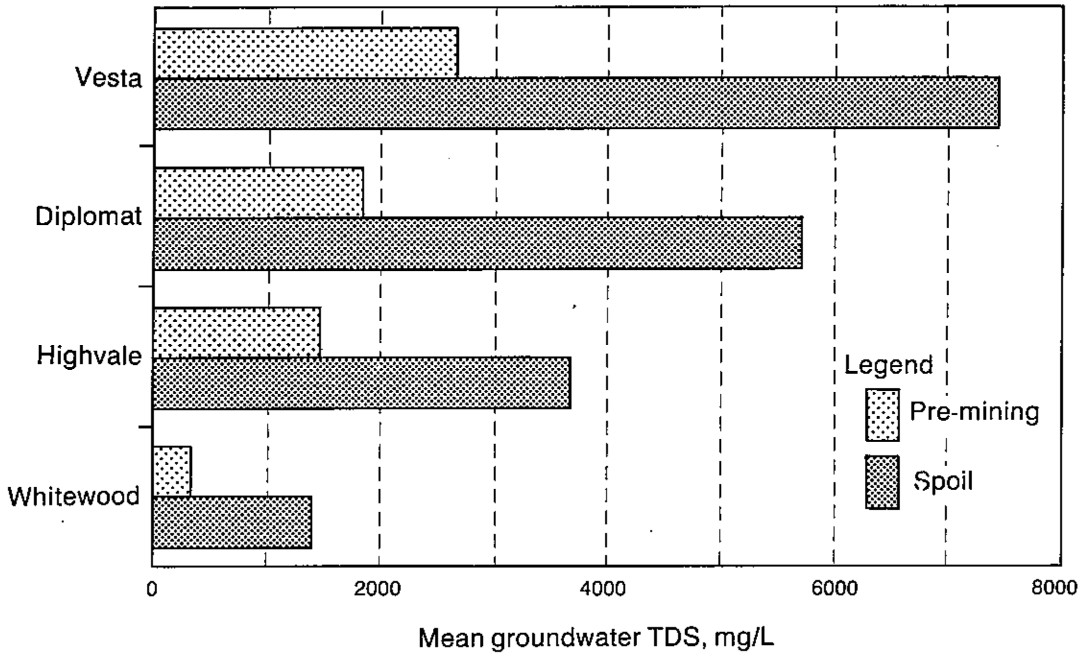

Figure 12. Comparison of total dissolved solids concentration of groundwater in pre-mining aquifers and mine spoil in the plains of Alberta (After Trudell et al. 1988).

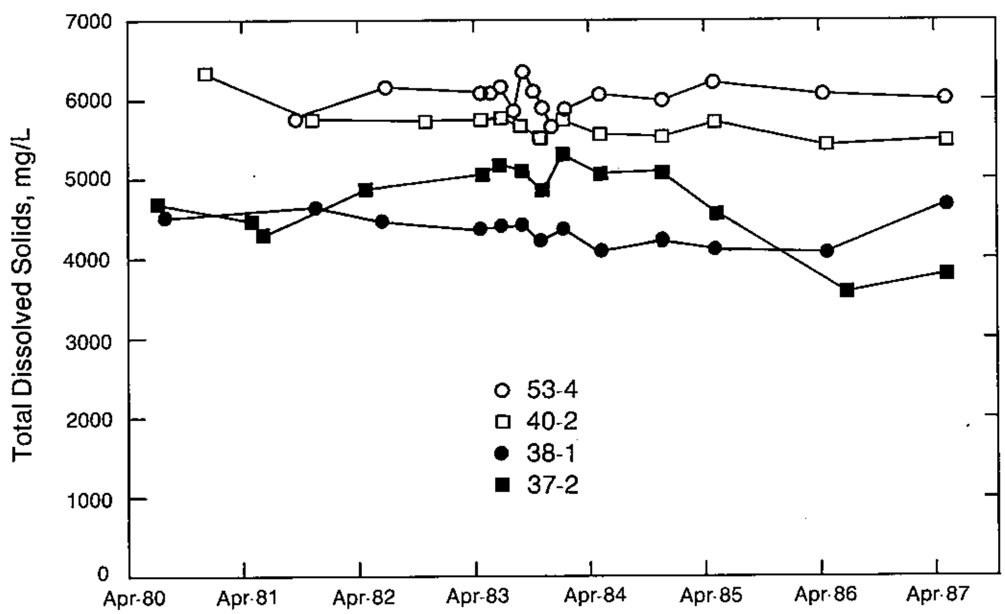

Figure 13. Hydrograph of total dissolved solids (1981–1987) for selected wells completed in mine spoil (Modified from Trudell et al. 1988).

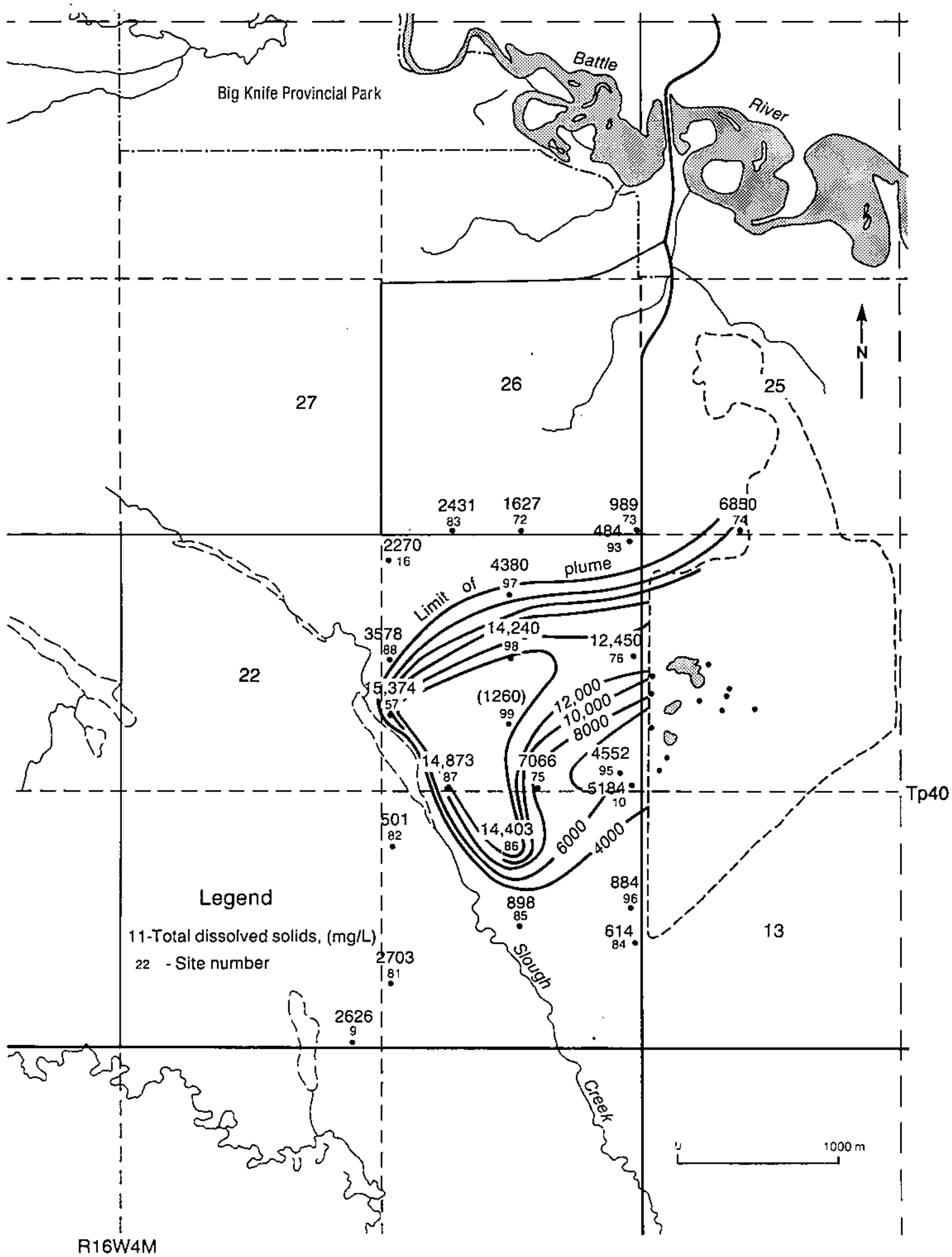

Figure 14. Plume of spoil derived groundwater (After Trudell et al., in press).

reclamation; and (2) rock material that was originally beneath the water table is exposed to atmospheric weathering processes as a result of mining. This enables the conversion of some insoluble minerals into readily soluble oxidation products.

On the basis of actual groundwater chemistry and experimental weathering of overburden materials, it appears that the principal source of salt in spoil groundwater is a solution of salts that were previously precipitated in the soil zone (Moran et al. in prep). The climate of the plains region is characterized by a moisture deficit, with potential evapotranspiration considerably in excess of precipitation. The vast majority of the plains region is underlain by fine-grained rock and sediment, which serves to retard downward drainage of infiltration, and therefore to minimize leaching of salts out of the soil zone. The interaction of these two factors, one geologic and the other climatic, results in the entire plains region being characterized by landscape settings that contain soil profiles with accumulations of secondary salt. Although there are variations in the amount of the landscape that contains saline soils (Pettapiece 1989), soils in the Short Grass, Mixed Grass, Fescue Grass, and Aspen Parkland Ecoregions (Figure 2) are generally characterized by appreciable salt within the profile (Strong and Leggat 1981).

In places in the Lower Horseshoe Canyon Coal Zone, and possibly in the Lethbridge and Taber Coal Zones, the overburden contains materials that were deposited in a marine environment (Maslowski Schutze et al. 1986). Our studies, as well as studies elsewhere in North America, indicate that materials that were deposited in a marine environment tend to contain oxidizable sulfur either in the form of pyrite or bonded in organic materials (Caruccio et al. 1977; Horne et al. 1978). For mines in such a setting, weathering of the freshly exposed overburden would result in the generation of additional salt, over and above the secondary salt present in the weathered horizon of the pre-mining landscape. Evidence suggests that oxidation of either organic or pyritic sulfur in previously unweathered overburden does not make a significant contribution to the dissolved salt load at the sites we have studied. This is contrary to the role postulated for sulfur oxidation elsewhere in western North America (Groenewold et al. 1983; Moran and Cherry 1977; Moran et al. 1978a).

4.4.2 Conclusions

We concluded that much, if not most, of the dissolved salt load in the spoil groundwater at the sites studied resulted from dissolution of secondary salts that had been accumulated over time in the soil zone of the pre-mining overburden. It is concluded, therefore, that future surface mines in the plains region will contain groundwater with mean TDS of 5000 to 7000 mg/L, and will be generally saturated with respect to calcite, dolomite, and gypsum.

The brackish nature of groundwater in mine spoil appears to be an inevitable consequence of mining in the plains region of Alberta. The geologic nature of the materials combined with the climate of the region lead to this chemical composition for the groundwater. There is no known method of materials handling that would alter the chemical make up of the groundwater in mine spoil in this region.

4.5 HYDROLOGIC REGIME OF RECLAIMED LANDSCAPES

4.5.1 Spoil Resaturation

The most important aspect of the hydrologic regime in determining the success of reclamation is the proximity of the water table to the land surface. The location of the water table in a reclaimed area is determined by the process and rate of spoil resaturation, which in turn varies as a function of landscape setting and hydraulic conductivity of the spoil material. The process of spoil resaturation is fundamentally different in lowland and upland settings. The rate of spoil resaturation and the rate at which stable steady-state equilibrium conditions are established are governed by the hydraulic conductivity of the spoil. Combining these two factors gives a four component model of spoil resaturation (Moran et al. 1987b).

4.5.1.1 Lowlands – High Permeability Spoil. During the early stages of spoil resaturation, all spoil regardless of composition appears to be characterized by relatively large values of hydraulic conductivity. Groundwater recharge in lowland settings occurs more or less continuously by leakage from both deep and shallow permanent ponds (Figure 15) (Schwartz and Crowe 1987). Ephemerally ponded depressions and infiltration beneath unponded sites also contribute to the recharge in lowland settings (Trudell et al. 1986). Leakage of water from ponds is initially very rapid resulting in rising water levels that saturate the spoil at rates as great as one metre per year. In spoil consisting largely of till or non-sodic bedrock, the hydraulic conductivity remains high, with values typically in excess of 10^{-7} . Rapid resaturation of the spoil continues until the rising groundwater level causes the hydraulic gradient to decrease and pond leakage slows. In mine sites with high permeability spoil, recovery of groundwater levels to the stable post-mining steady-state configuration is rapid, generally requiring no more than five to ten years (Moran et al. 1989).

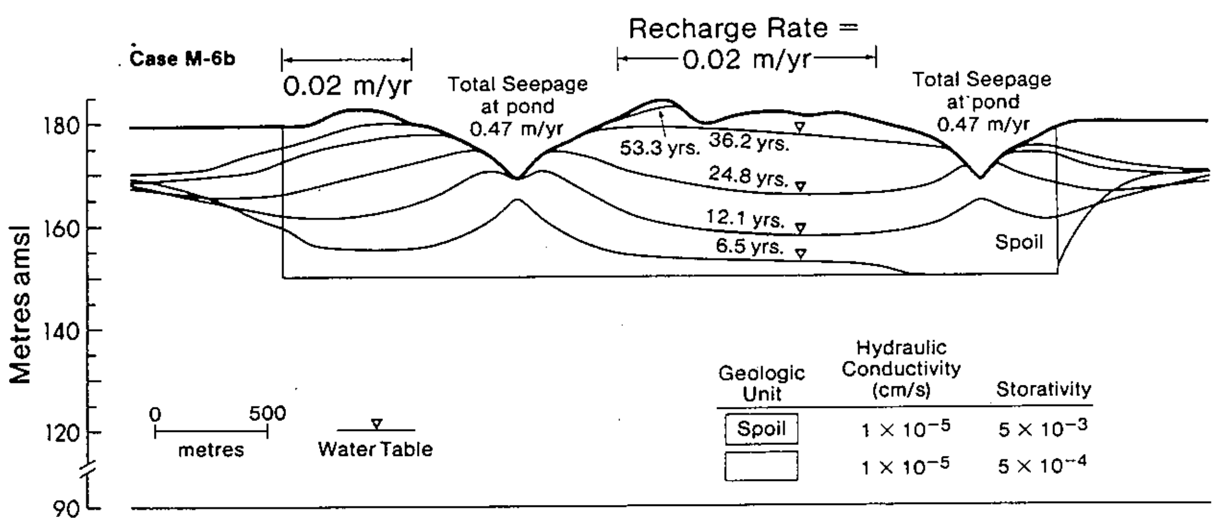

Figure 15. Example of simulated water-level recovery in spoil (After Schwartz and Crowe 1987).

At the western end of Diplomat Mine, the PHRP project instrumented an area of about 1 490 000 m^2 of which about 807 500 m^2, or about 54 percent comprises lowland (Figures 16 and 17). The annual rate of recharge in this instrumented site is calculated to be about 1.9×10^{-2} m^3/m^2, about 4.75 percent of the annual precipitation (Table 3). Large, deep ponds account for 57 percent of the recharge with non-ponded areas second most important, accounting for 20 percent of the recharge (Moran et al. 1989).

4.5.1.2 Lowlands – Low Permeability Spoil. In lowland settings where the spoil contains abundant sodic bedrock, slaking and swelling of the spoil results in a reduction of the initial hydraulic conductivity values to much lower values, generally less than 10^{-9}. This results in a significant reduction in the rate of pond leakage and spoil resaturation. Recovery of groundwater levels to the stable post-mining steady-state configuration is slow, requiring at least several decades in mine sites with spoil having these low hydraulic conductivity values (Moran et al. 1989).

At the western end of Vesta Mine, the PHRP project instrumented an area of about 942 500 m^2 of which about 180 000 m^2, or about 20 percent comprises lowland (Figure 16 and 18). Moran et al. (1989) estimated that average total recharge in this area was between 0.15 and 0.20 m^3/m^2/year for the first eight years following reclamation. Since 1981, the rate of spoil resaturation has decreased significantly from its initial value to a total recharge flux of about 1.3×10^{-2} m^3/m^2, about 3.25 percent of the annual precipitation (Table 3). Thus, the average recharge rate between 1973 and 1980 was about 10 to 15 times as great as it was between 1981 and 1988. Small permanent ponds account for 61 percent of the recharge, with non-ponded areas second most important, accounting for 19 percent of the recharge.

4.5.1.3 Uplands – High Permeability Spoil. In upland settings, groundwater recharge occurs almost entirely by infiltration beneath unponded sites over the entire

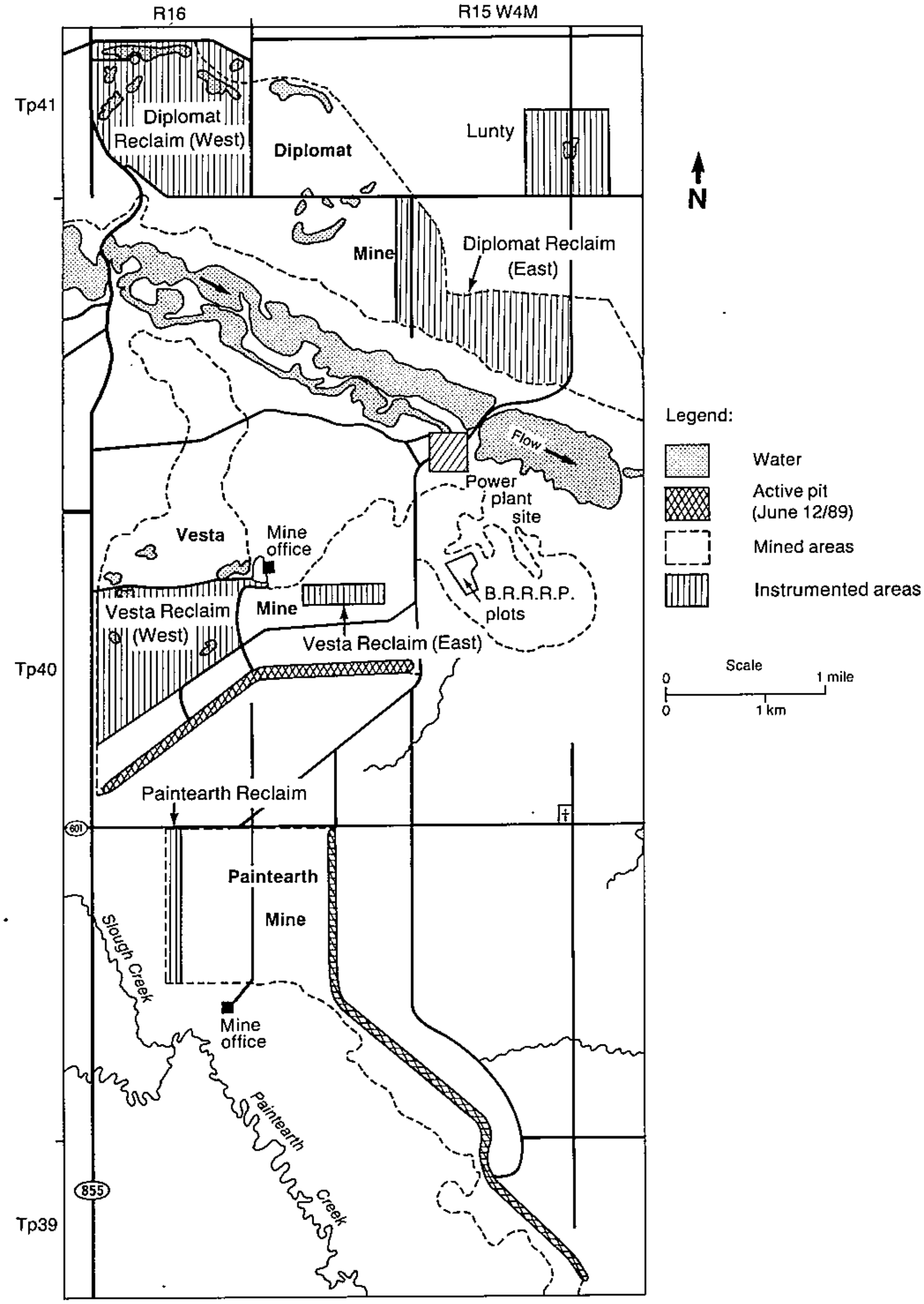

Figure 16. Key map for location of instrumented areas within the Battle River study area.

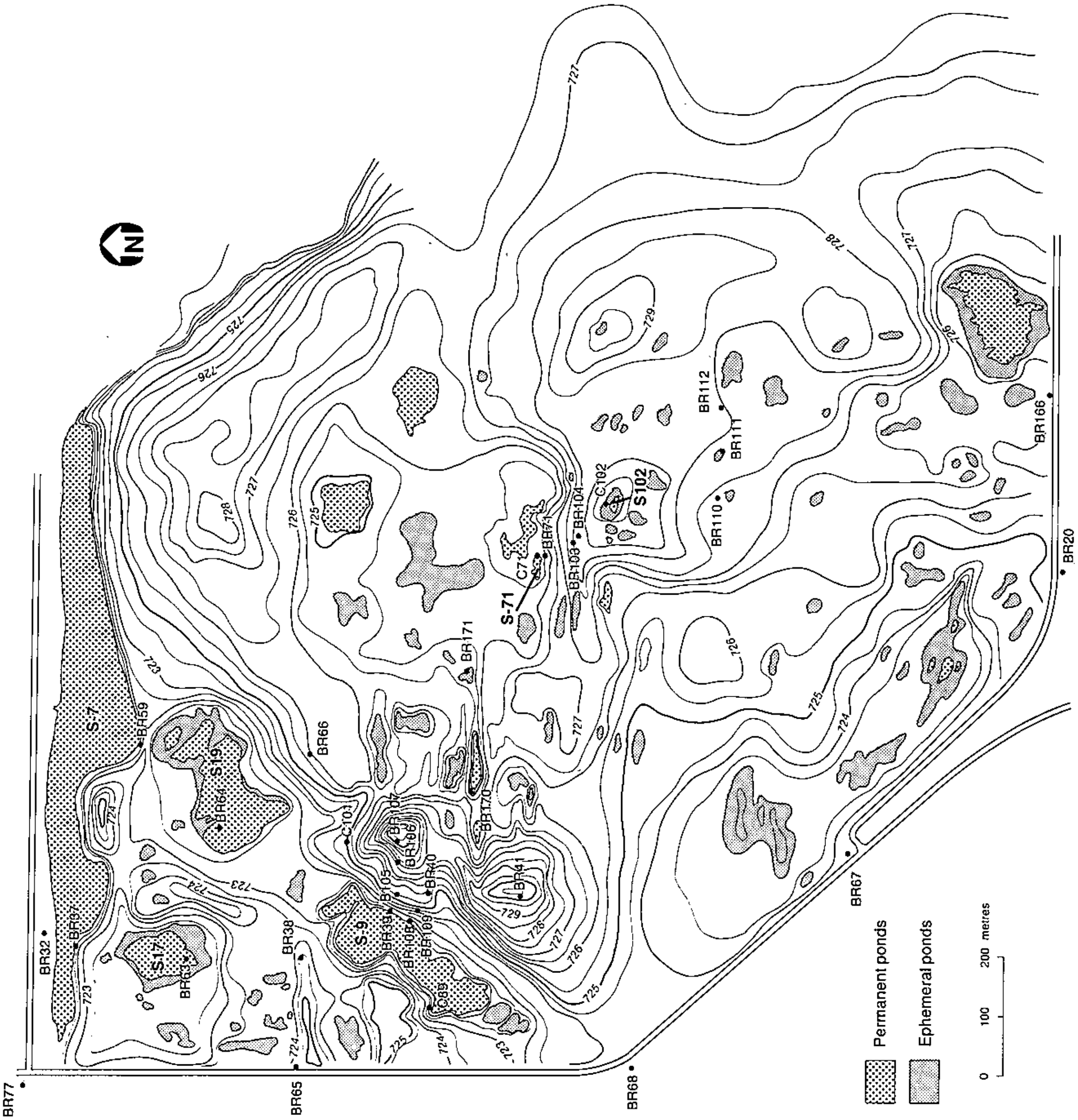

Figure 17. Map showing location of instrumentation in the reclaimed spoil at Diplomat Mine (western part).

Table 3. Recharge contributions from various landscape settings in reclaimed spoil at Diplomat and Vesta Mines. Source: Moran et al. 1989.

	Area (m^2)	Seepage Rate %	Recharge (m^3/m^2)	Recharge (m^3)	Recharge %
Vesta Lowland					
Ephemeral ponds	9,000	5.0	0.0220	198	8.6
Large ponds	30,425	16.9	0.0083	252	10.9
Non-ponded	127,735	71.0	0.0035	447	19.4
Small Ponds	12,850	7.1	0.1096	1408	61.1
Total	180,000		0.0128	2305	
Diplomat Lowland					
Ephemeral ponds	40,375	5.0	0.0583	2352	15.4
Large ponds	67,300	8.3	0.1285	8645	56.6
Non-ponded	649,825	80.5	0.0047	3054	20.0
Small Ponds	50,000	6.2	0.0243	1215	8.0
Total	807,500		0.0189	15266	
Vesta Upland					
Ephemeral Ponds	38,125	5.0	0.0220	839	18.3
Non-ponded	712,875	93.5	0.0035	2495	54.3
Small Ponds	11,500	1.5	0.1096	1261	27.4
Total	762,500		0.0060	4594	
Diplomat Upland					
Ephemeral Ponds	34,125	5.0	0.0583	1988	34.9
Non-ponded	614,250	90.0	0.0047	2887	50.6
Small Ponds	34,125	5.0	0.0243	829	14.5
Total	682,500		0.0084	5704	

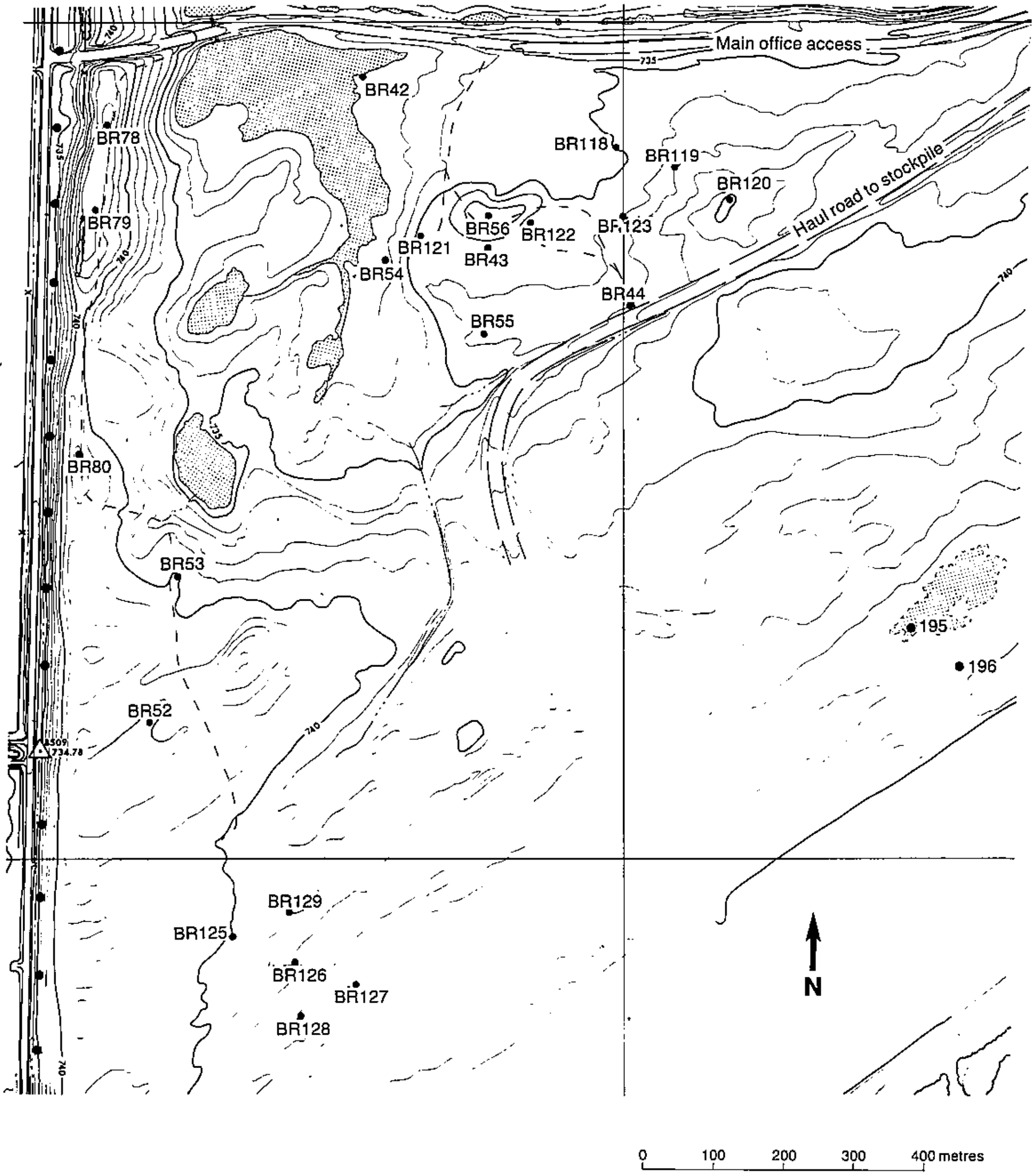

Figure 18. Map showing location of instrumentation in the reclaimed spoil at Vesta Mine.

landscape and beneath ephemerally ponded depressions and the few shallow permanent ponds that form in larger subsidence depressions. Where the hydraulic conductivity of the spoil is relatively high, steady-state equilibrium is achieved in 10 to 15 years, depending on the thickness of spoil and climatic conditions.

Upland settings were instrumented in two areas of Diplomat Mine. About 682 500 m^2, or 46 percent of the instrumented study area at the west end of the mine consists of upland areas (Figure 17). Three small instrumented sites in the eastern part of Diplomat Mine are also characteristic of upland settings (Figure 16). About 5 percent of the instrumented upland area at the western end of Diplomat Mine is occupied by permanently ponded depressions. Another 5 percent of the entire upland area is characterized by depressions that are ponded during snow melt and after heavy rain storms. The annual recharge rate in the instrumented upland setting at Diplomat Mine is about 8.4×10^{-3} m^3/m^2, about 2.1 percent of the annual precipitation (Table 3). Non-ponded sites account for 51 percent of the recharge with ephemeral ponds accounting for 35 percent of the recharge.

4.5.1.4 <u>Uplands – Low Permeability Spoil</u>. In upland settings where the hydraulic conductivity of the spoil is low, a much longer period, at least several decades, is required to reach steady-state conditions. As in lowland settings, the hydraulic conductivity of the spoil is initially high and water infiltrates rapidly beneath small depressions. As the spoil becomes saturated, slaking and swelling cause hydraulic conductivity to decrease. Small depressions that initially drained rapidly become the site of larger perched ponds as the rate of seepage declines and as a result of increased differential subsidence resulting from the seepage. Recharge from these depressions declines as a greater proportion of the water they contain is returned to the atmosphere by evaporation and evapotranspiration.

Upland settings were instrumented in two areas of Vesta Mine and at Paintearth Mine (Figure 16). About 762 500 m^2, or 80 percent of the instrumented study area at the west end of Vesta Mine consists of upland areas. An upland area of about 300 000 m^2 in the eastern part of Vesta Mine was instrumented with three piezometer nests and two neutron-probe access tubes (Figure 16). An upland area of about 500 000 m^2 at Paintearth Mine was instrumented with three piezometer nests and six neutron-probe access tubes (Figure 16). About 5 percent of these instrumented upland areas are occupied by depressions that are ponded during snow melt and after heavy rain storms. Permanently ponded depressions are present but occupy no more than about another 1.5 percent of the entire upland area. The annual recharge rate in the instrumented upland setting at Vesta Mine is calculated at 6.0×10^{-3} m^3/m^2, about 1.5 percent of the annual precipitation (Table 3). Non-ponded sites account for 54 percent of the recharge with small permanent ponds second most important, accounting for 27 percent of the recharge.

4.5.2 Steady State Equilibrium Hydrologic Regime

The data collected by the PHRP project suggest that recharge in lowland settings is about twice that in upland settings, regardless of hydraulic conductivity. Furthermore, the model indicates that in east-central Alberta, this difference in recharge rate is sufficient to produce differences in the post-mining hydrologic regime. Where recharge is less than about 1.5 to 2.0 percent of the total annual precipitation, groundwater flow is able to remove the water supplied and the water table does not interact with the land surface. Where recharge is about 3.0 to 4.5 percent of the total annual precipitation, however, groundwater flow is not able to remove the water supplied and the water table rises to the land surface.

The steady-state hydrologic regime in reclaimed landscapes is essentially the same as that prior to mining and in analogous adjacent undisturbed settings. The principal difference lies in the dynamics of ephemerally ponded upland depressions. In reclaimed landscapes, these depressions are expected to be subject to more severe seasonally wet conditions than in unmined landscapes. Water infiltrating beneath small depressions generally moves downward until it encounters a zone of lower hydraulic conductivity, which retards flow. The greater the depth to such a barrier, the more water can be drained away from the pond in the depression and the quicker the ponding dissipates. Sodic bedrock, which underlies surficial deposits and constitutes a significant hydraulic barrier in most mining areas in the plains of Alberta, is encountered at variable depths but in places is quite deep. In the Battle River mining area, for example, as much as 10 m of glacial till overlies sodic bedrock in parts of the unmined landscape. Subsequent to mining, up to 1.5 m of till is generally replaced over the dominantly bedrock-derived spoil. The decrease in permeability at the top of the spoil is expected to impede downward infiltration and result in perching of ponds above the regional water table.

The steady-state water table in lowland settings is close to the land surface over much of the area, generally being no more than one to three metres deep (Figure 6). Once the post-mining equilibrium is established, the large ponds are sites of groundwater discharge, at least during part of the year. In upland settings, the steady state water table is at considerable depth below the land surface, at least five to ten metres below the surface in most areas. The water table approaches the land surface only beneath larger permanent and semi-permanent upland ponds (Figure 6).

At both Diplomat and Vesta Mines, ponds or sloughs were present in the pre-mining landscape. At Diplomat Mine, the pre-mining landscape was characterized by numerous small sloughs scattered across the area, reflecting the overall poorly-integrated drainage pattern. In some cases, ponds in the reclaimed landscape are in approximately the same location as the larger pre-mining sloughs. In most cases, however, the location of post-mining ponds has been controlled by the mining process and by differential subsidence. At Vesta Mine, the situation is similar, but with fewer ponds in both pre-mining and reclaimed settings. Although the area of ponding at both mine sites was generally similar before and after mining, the ponds in lowland settings in the post-mining landscape are generally fewer, larger, deeper, and tend to be more permanent, than ponds in the pre-mining setting. The net result is that the surface hydrology and distribution of sites of groundwater recharge and of soil salinity in reclaimed land should be more or less similar to the natural landscape.

4.5.3 Discussion

The fundamental elements of the hydrologic regime that determine the success of reclamation are the depth to water table and the balance between groundwater recharge and discharge within the site. The hydrologic regime of reclaimed landscapes is controlled by: (1) the thickness of the overburden relative to the thickness of coal that was removed; (2) the handling and placement of overburden during the mining operation; (3) climate; and (4) the hydraulic conductivity of the spoil (Figure 19). The thickness of the overburden relative to the thickness of coal removed, combined with the handling and placement of overburden during the mining operation, govern the configuration of the reclaimed landscape. The configuration of the reclaimed landscape and the climate determine the degree of surface ponding within the reclaimed landscape. The number, depth, and area of surface ponds in the reclaimed landscape determine the proximity of the water table to the land surface.

Within this model, two of the elements, the climate and hydraulic conductivity of the spoil, are fixed for any particular mine site. The third element, overburden thickness, varies throughout a mine site, but is fixed at each location within the site. The only element of the model over which the miner or regulator can exercise control is the material handling and placement. In this section, we briefly discuss generalizations of PHRP results as they concern the three relatively fixed elements of the model. The potential for managing the hydrologic regime by material placement is discussed in the final section of the report.

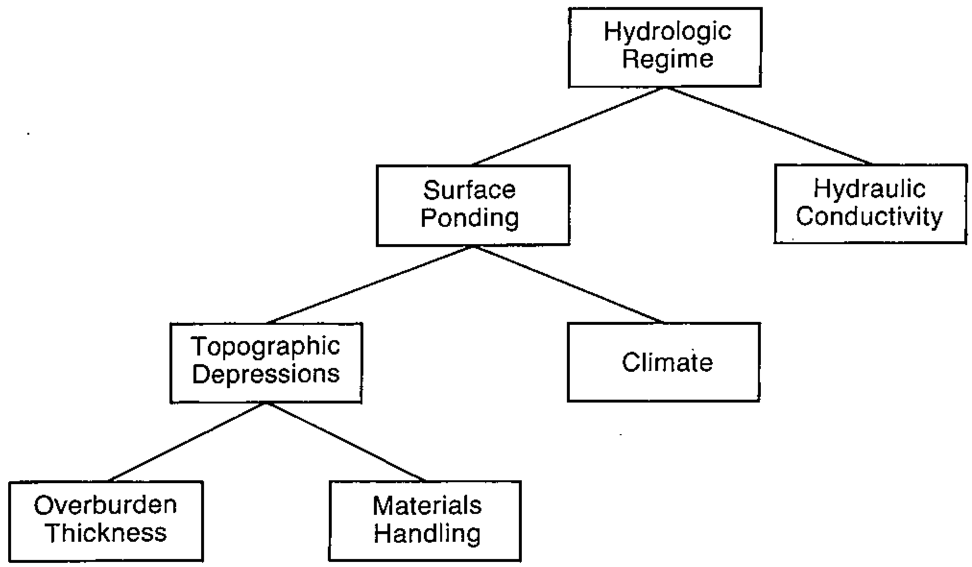

Figure 19. Factors that control the hydrologic regime of reclaimed landscapes.

4.5.3.1 Hydraulic Conductivity. The hydraulic conductivity of the spoil is the primary control on the rate at which the post-mining steady-state equilibrium situation is established. In general, the majority of mines developed in the Lower Horseshoe Canyon Coal Zone will be characterized by overburden that is dominantly fine-textured bedrock. As a result, it is anticipated that mine spoil in this coal zone will have hydraulic conductivity characteristics similar to Vesta and Paintearth Mines, with mean values on the order of 10^{-9} m/s. On this basis, we conclude that decades to centuries will be required for steady-state conditions to be attained in these mine sites. In the Ardley Coal Zone it is anticipated that the majority of mines developed will have mine spoil characterized by hydraulic conductivity similar to Highvale Mine, with mean values on the order of 10^{-7} m/s. On this basis, we conclude that 10 to 20 years will be required for steady-state conditions to be attained in these mine sites.

4.5.3.2 Climate. The most important aspect of climate as it influences the hydrologic regime in reclaimed landscapes is the availability of water to produce ponds. The availability of water is a function of the magnitude and timing of precipitation and the potential for evaporation and evapotranspiration. In general terms, as one moves from the Lake Wabamun mining area southeastward across the plains of Alberta, the availability of water decreases, precipitation decreases, and evaporative losses increase. As was discussed in Section 2.3, the zonation of the plains region into a series of ecoregions reflects this trend. Thus, for a depression of a given size, the potential for ponding, and the frequency and duration of ponding decreases to the southeast. Hence, in order to form a pond of the same size at Sheerness as one at Highvale, the contributing drainage area must be much larger at the former site than at the latter. The implication for this decrease in potential for ponding toward the southeast is that there is much less likelihood for shallow water table conditions to develop at Sheerness than at Camrose-Ryley or Genesee. In the event that permanent or semi-permanent ponding should develop at a mine in the Short Grass or Mixed Grass Ecoregion, however, the potential for salinization is much greater than it is farther to the northwest. In assessing the potential for ponding at a particular mine site in the Aspen Parkland, Short Grass or Mixed Grass Ecoregions, the occurrence and setting of surface-water in the pre-mining landscape should be carefully evaluated. Where surface ponding is uncommon and infrequent, there is much less need to be concerned with designing the landscape to minimize surface ponding. Where ponds in the pre-mining landscape are numerous and long lived, however, it is important that the landscape be designed to minimize the potential for ponding.

4.5.3.3 Overburden Thickness. If coal could be removed without disturbing the overburden, the post-mining landscape would be simply lowered by an amount equivalent to the thickness of the removed coal. In reality, however, the mining process disturbs the overburden and creates an additional 25 to 30 percent of pore space. The initial reclaimed surface is therefore higher than it would be if there were no disturbance. As water begins to enter the newly created pore spaces, the physical structure of individual fragments of spoil either collapses, or swells and collapses, causing the overall spoil mass to compact (Dusseault et al. 1983, 1984, 1988). This compaction results in a lowering of the reclaimed surface, both by area-wide subsidence and by differential subsidence, which creates pits and depressions. The final bulking factor for mine spoil in the plains of Alberta appears to be on the order of 20 percent. Thus, the final spoil thickness is about 20 percent greater than the original thickness of the undisturbed overburden.

On the basis of the discussion in the previous paragraph, it is possible to predict in advance of mining, areas where the final post-mining landscape will be lower than the pre-mining landscape, and therefore lower than the surrounding unmined landscape. These areas will tend to become hydrologic lowland sites in the reclaimed landscape, the characteristics of which were described in Section 4.5. Lowland sites accumulate surface water and become the locus of discharge for groundwater flow systems. In some instances, the landscape configuration can be designed to minimize, or even eliminate lowland sites. In most cases, however, lowland sites will persist with certain inherent limitations to post-mining capability. The following expression describes the relationship between the thickness of coal to be mined (T_C), overburden thickness (T_O) and bulking factor (B) required for lowland conditions to develop:

$$T_OB < T_C$$

Upland settings develop when $T_OB > T_C$. Using this relationship, with bulking factors of 20 and 25 percent, lowland conditions will result when the overburden thickness is less than 5 and 4 times the thickness of the coal, respectively.

5. IMPACTS OF MINING AND RECLAMATION ON POST-MINING LAND USE

The PHRP focussed on three primary concerns related to surface mining of coal in the plains region of Alberta: (1) to determine the impacts of surface mining on the groundwater supplies within and in the areas surrounding potential mining areas; (2) to evaluate the potential that agricultural capability of reclaimed landscapes would be restored to pre-mining levels; and (3) to evaluate the concern that the agricultural capability of reclaimed landscapes might be degraded over time by groundwater induced salinization.

5.1 IMPACT OF SURFACE MINING ON GROUNDWATER RESOURCES

The water supplies used by the rural population in areas of potential surface mining of coal in the plains of Alberta are derived almost entirely from groundwater in either fractured coal beds or sandstone aquifers overlying the coal. In the Battle River mining area, for example, 75 percent of the 28 domestic wells, for which the producing zone could be identified, were completed in the two coal beds that are being mined (Trudell et al. 1986). In the Wabamun mining area, 196 water wells, for which the completion zone could be identified, occurred in the area underlain by the Ardley Coal Zone; 18 percent were completed within the coal, 62 percent in sandstone overlying the coal, and 17 percent in glacial drift overburden (Trudell 1986).

5.1.1 Groundwater Supplies within Mine Areas

Surface mining removes the fractured coal bed or sandstone aquifers and replaces them with spoil, thereby decreasing the capability of the area to supply groundwater and potentially degrading the chemical quality of adjacent areas.

The hydraulic properties of mine spoil in the plains of Alberta, as described in Section 4.3, preclude development of water supplies above the base of disturbance. Pre-mining overburden consists of dominantly silty to clayey bedrock or glacial drift that have very low hydraulic conductivities (Figure 10) [Trudell and Faught 1987; Trudell et al. 1987]. Even where sandstone comprises a significant proportion of the overburden, the interstitial smectitic clay renders the hydraulic conductivity very low except where the sandstone is fractured. Cast overburden initially has a loose structure that allows relatively rapid flow of infiltrating groundwater (Trudell et al. in prep). As water comes into contact with the spoil material, however, the structure of individual fragments collapses (Dusseault et al. 1988) and the secondary porosity is lost. The hydraulic conductivity of the cast overburden rapidly decreases to values less than those of the pre-mining coal aquifers but somewhat greater than those of the original overburden (Figures 9 and 10) [Trudell et al. in prep]. At these values of hydraulic conductivity, the spoil is not capable of supplying water to wells (Trudell 1986; Trudell et al. 1986; Trudell and Moran 1986).

5.1.2 Alternative Post-Mining Groundwater Supply

Aquifers capable of replacing the shallow coal aquifers that were removed by mining are generally not available, although in places they do occur. Laterally persistent, sheet-like sand bodies occur in the Bearpaw Formation beneath the lowermost coal in the Horseshoe Canyon Formation at sites such as at the Battle River study area (Figure 4) [Maslowski Schutze et al. 1986]. These sandstone bodies generally have sufficient thickness and hydraulic conductivity to produce an adequate water supply for individual farmsteads (Trudell et al. 1987). The geologic and hydrologic settings of these sand bodies, however, generally result in water that is too saline for human, and in places, animal consumption. The water in these sand beds is generally situated at depths below actively flushed groundwater flow systems. As a result, flow paths and residence times are long, flow velocities are low, and diffusion from the superjacent and subjacent marine shale beds is an important chemical process. The resulting groundwater is brackish and dominated by sodium chloride.

At sites where the sand beds in the Bearpaw Formation are recharged through deeply incised glacial meltwater valleys, such as in the eastern part of the Battle River study area (Trudell et al. 1986, Trudell et al. 1987), the water quality in these aquifers can be acceptable for human consumption. Where the water quality is acceptable, these sand beds offer the best option to replace water supplies lost as a result of mining.

At mine sites higher in the Horseshoe Canyon Formation such as the Camrose-Ryley area, or in the Ardley Coal Zone such as the Lake Wabamun mining area, the best possibility of developing post-mining groundwater supplies involves the development of deeper, laterally persistent coal beds or discontinuous sand bodies. Inadequate well yield and chemical quality are potential limitations to development of replacement water supplies in deeper coal beds. It has been shown that the hydraulic conductivity of coal decreases with depth, presumably as a result of a decrease in number and size of fractures (Moran et al. 1978a, 1978b). Discontinuous sand bodies that range in thickness from a few metres to tens of metres and in width from a few hundred metres to several kilometres are widespread in coal-bearing sequences through the plains of Alberta. Their location is difficult to nearly impossible to predict without detailed geological investigations. In addition, in many instances, the hydraulic conductivity is inadequate because of interstitial clay and minimal fracturing, and the chemical quality of the water is inadequate for reasons outlined above (Trudell 1986).

5.1.3 Impact on Regional Groundwater Resources

At the time that PHRP was initiated, there was considerable concern that surface mining might disrupt groundwater supplies, not only within mine areas, but also in areas adjacent to the mined-out area, potentially at considerable distance from the mines. In order to assess the validity of this concern, data were collected on the aquifers and groundwater flow patterns at distances as great as 5 to 10 km from the mine area (Trudell et al. 1987; Trudell and Faught 1987).

In both of the study areas that were investigated in detail as part of the PHRP project, the Battle River mining area (Trudell et al. 1986) and the Lake Wabamun mining area (Trudell and Moran 1986), the effects of mining on groundwater levels were limited to the immediate vicinity of the mine. The data show that water levels are affected only in wells that are a few hundred metres from the mine. At distances greater than about one kilometre from the mine, no effect on water levels in wells has been observed. The data also indicate that the drawdown effects of mine pits do not propagate uniformly in all directions. This differential drawdown is believed to be related to the directional anisotropy in hydraulic conductivity of coal which is related to the orientation of joints in the coal, as reported for the Battle River area by Vogwill (1976). Appreciable drawdown is not observed until two conditions occur, first that the active mine pit be within one kilometre of a site, and second that the site, with respect to the active pit, aligns along the direction of the orientation of the major joint set in the coal.

Data from the Battle River study area provide an example of the relationship between distance and direction from the mine pit, and impact on water level in wells. The hydrograph depicting the water level in the Battle River Bed at site BR6 shows an abrupt but minor drop in water level in September 1981 with the opening of Paintearth Mine, 1350 m to the east (Figure 20). The significant drop in water level beginning in June 1986 reflects dewatering due to the presence of the southwestern end of Vesta Mine, about 800 m to the northeast. In this case site BR6 and the active pit align along the major cleat direction (N 58° E) (Trudell et al. in press) of the coal. It is noteworthy that in July 1985, when the Vesta pit was 900 m away from site BR6, and alignment with the major cleat direction of the coal did not occur, no significant change in the water level was observed at site BR6.

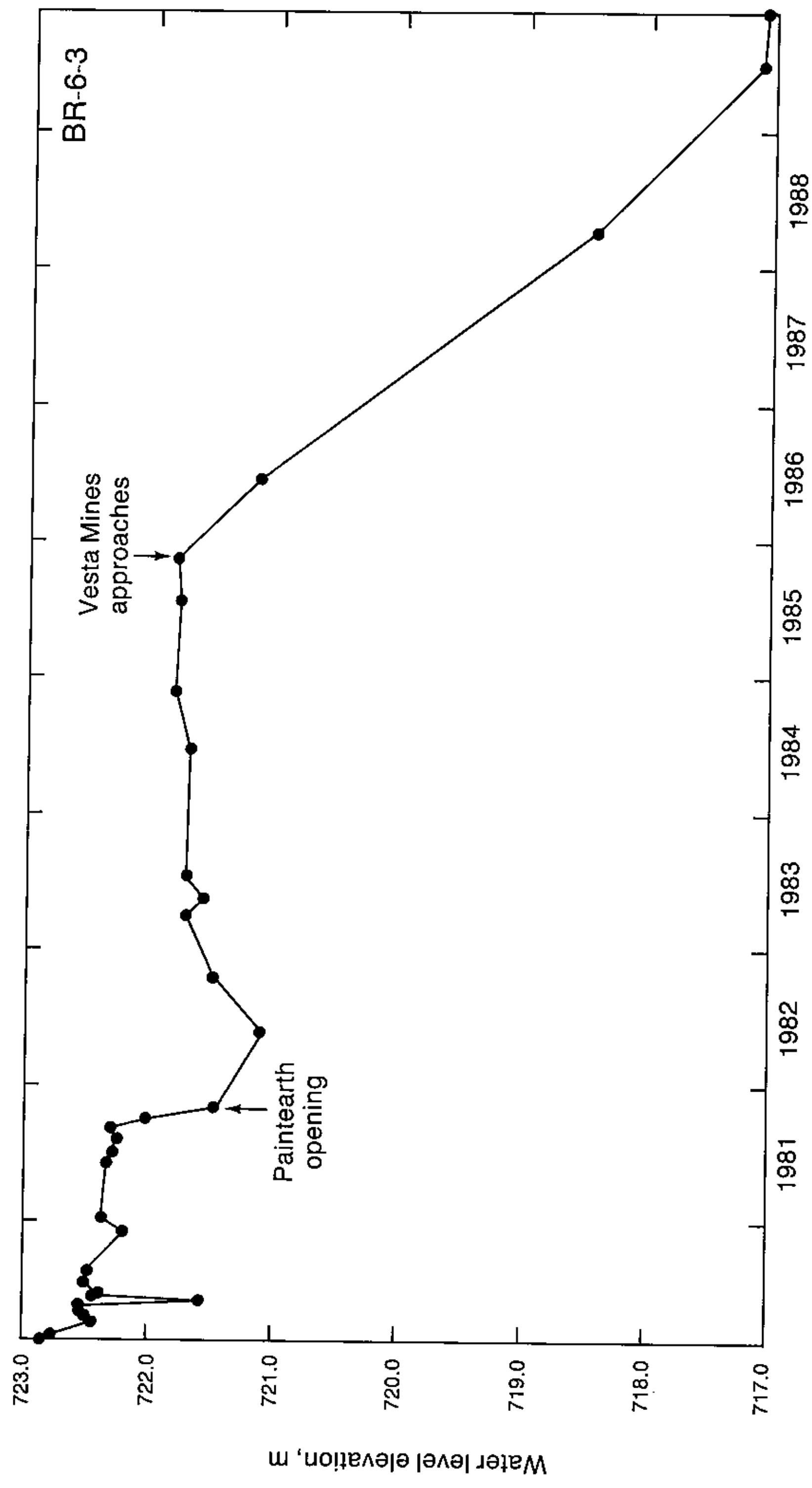

Figure 20. Water level hydrograph for wellcompleted in coal (Battle River Bed) at site BR6.

A similar effect is evident at site BR3, which is situated about 200 m north of Paintearth Mine; piezometer BR3-2 is completed in the lower coal, the Battle River Bed, and piezometer BR3-3 is completed in the upper coal, the Paintearth Bed (Figure 21). The initial box cut of Paintearth Mine was opened about 1.5 km west of the site in 1981. Mining progressed toward the east so that each successive cut was closer to site BR3. Piezometer BR3-3 showed no evidence of the mine until the water level began to fall in early 1984 (Figure 21) when the active pit was about 650 m to the west.

The localized effect of mining on groundwater levels has been observed at mines throughout the plains of western North America that, like the sites studied in Alberta, are located in areas of groundwater recharge (Van Voast et al. 1978, Van Voast and Reiten 1987, Moran et al. 1978b). At mines situated in areas of regional groundwater discharge, significant regional effects on groundwater levels can be expected at distances of many kilometres from the mines. Significant drawdown of water levels in wells have been reported from only two mining areas in the plains of western North America – at Coronach, Saskatchewan (N. Worsley, Saskatchewan Power Corporation, personal communication, Sept. 4, 1987) and Decker, Montana (Van Voast and Reiten 1987) – both of which are situated in regional groundwater discharge areas.

All surface mines in Alberta from which groundwater data are available are situated in recharge areas and as a result, are not expected to affect regional groundwater levels. Detailed investigations at Whitewood Mine (Alberta Environment 1979b), and limited data that are available from other mining areas in the plains of Alberta including the Camrose-Ryley area (CanPac Minerals Ltd. 1975), the Sheerness mining area (Alberta Environment 1977), and the Genesee area (Alberta Environment 1979a) all indicate that groundwater recharge dominates. No existing or potential mines in the plains of Alberta are known to be situated in areas of regional groundwater discharge. It is, therefore, unlikely that any mines in the plains region of the province will result in groundwater impacts beyond the immediate vicinity of the mining operation. On this

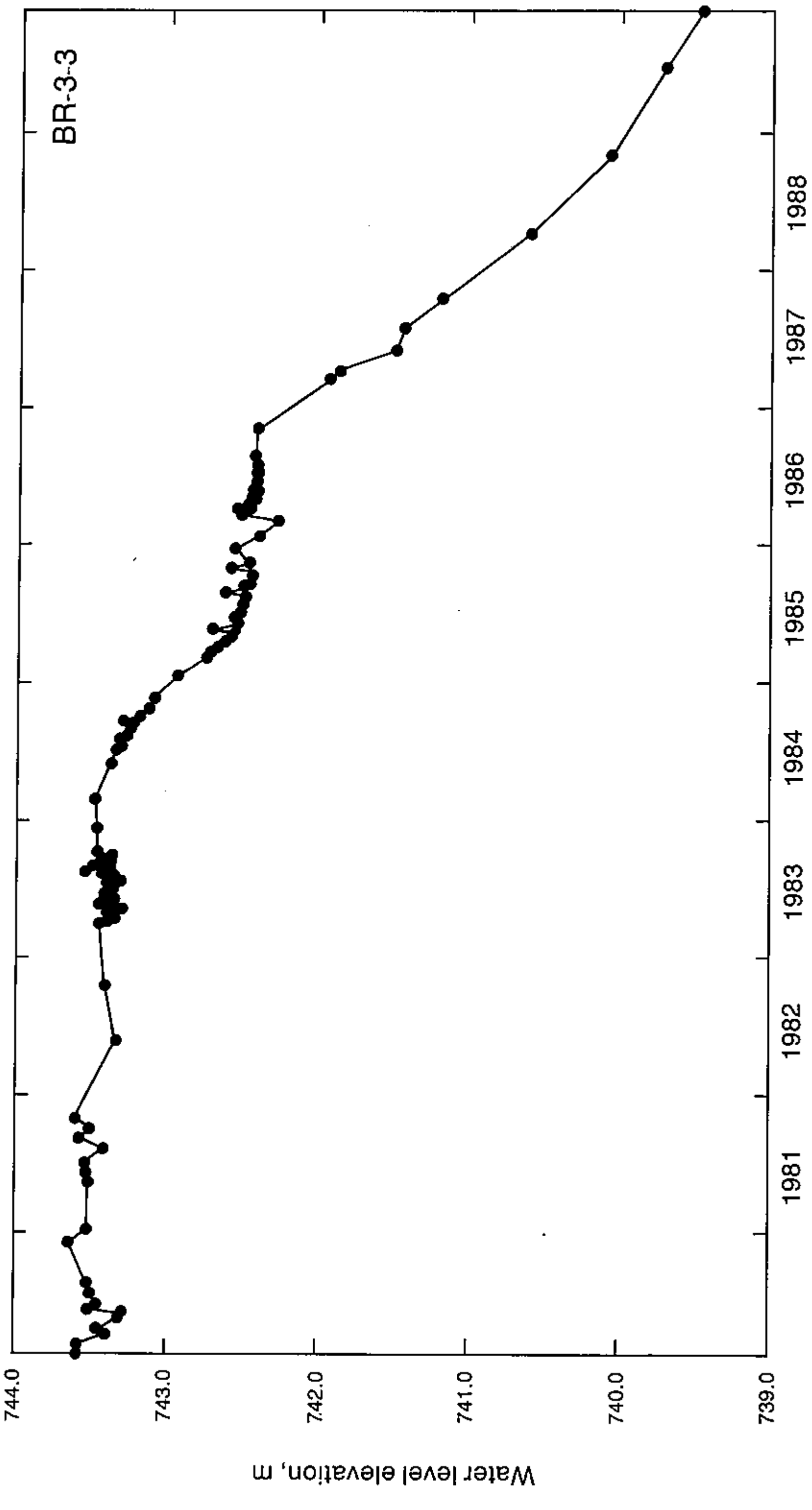

Figure 21. Water level hydrograph for well completed in coal (Paintearth Bed) at site BR3.

basis, we conclude that the initial concern that mining might be deleterious for regional groundwater supplies in the plains of Alberta was unfounded.

5.1.4 Potential for Contamination of Surface Water

Groundwater discharging from mine spoil does not appear to pose a significant threat to the chemical quality of surface water. Along the 10 km reach of the Battle River valley, where it traverses Diplomat and Vesta Mines in the Battle River mining area, Trudell (1988) identified and sampled 25 springs and seeps. Fourteen of these springs discharged spoil-derived groundwater and the remainder represent groundwater discharge from unmined aquifers. The discharge from the spoil-derived springs and seeps constituted about twice that of the unmined aquifers (103 vs 50 m^3/d), but the salt loading was more than four times as great (449 kg/d vs 106 kg/d). The impact of these discharges on the Battle River, however, is almost undetectable. The worst case scenario would involve low flow in the river late in the summer. The salt loading of the river under these conditions is calculated at 23 621 kg/d. This is based on the minimum long-term average daily flow recorded in the Battle River at a Water Survey of Canada gauging station 8 km upstream from the study area (53,200 m^3/d), combined with the mean fall TDS concentration of the Battle River during the period 1980 to 1982 (444 mg/L). Under these conditions, the addition of the entire salt loading from spoil-derived springs represents an increase of only 1.9 percent in the salt loading in the river (Trudell 1988).

5.2 AGRICULTURAL CAPABILITY OF RECLAIMED LANDSCAPES

Dryland agriculture is the dominant land use both before and subsequent to surface mining in most of the plains region of Alberta. One of the most important concerns related to surface mining of coal in Alberta is that the agricultural capability of reclaimed land be equivalent to that of the land prior to mining.

As discussed in Section 4.2, mining mixes the pre-mining soils to produce a reconstructed soil mantle of uniform thickness with properties that are an average of the pre-mining soil. The initial capability of the reconstructed soil also reflects a mix of the pre-mining capability. The agricultural capability of reconstructed landscapes is more uniform than, and is generally not as good as the best nor as poor as the lowest, capability in the pre-mining landscape (Macyk 1987). This initial capability, however, is altered once the reclaimed site begins to resaturate. Water moving on and beneath the soil surface initiates physical and chemical changes that alter the initial capability of the landscape to support agricultural operations. Some of these changes, such as leaching of soluble salts, improve the capability, whereas others, such as differential subsidence and ephemeral ponding, result in degradation of the capability.

5.2.1 Leaching Improves Capability

The salinity and sodium content of reconstructed soils in well drained, upland sites in the Battle River area has been observed to decrease between 1984 and 1987 (Moran et al. 1987a). This trend, as represented by Figure 22, was observed in the topsoil at seven of nine locations. The pattern was somewhat more complex in the subsoil, with salinity and sodium concentration decreasing at some depths and increasing at others. The overall pattern is consistent with downward flushing of salts with no evidence that sodium is moving upward from the spoil into the subsoil. Moran et al. (1987a) concluded that the overall capability of the reclaimed landscape in upland settings is improving over time relative to the inital post-reclamation conditions.

5.2.2 Density and Agricultural Capability

Discrete layers of more densely compacted material, which are formed by dozers during grading, and scrapers during placement of subsoil and topsoil, form barriers to infiltrating water and to root penetration. Where these compacted layers or pans persist for extended periods of time they can significantly decrease the capability of the post-

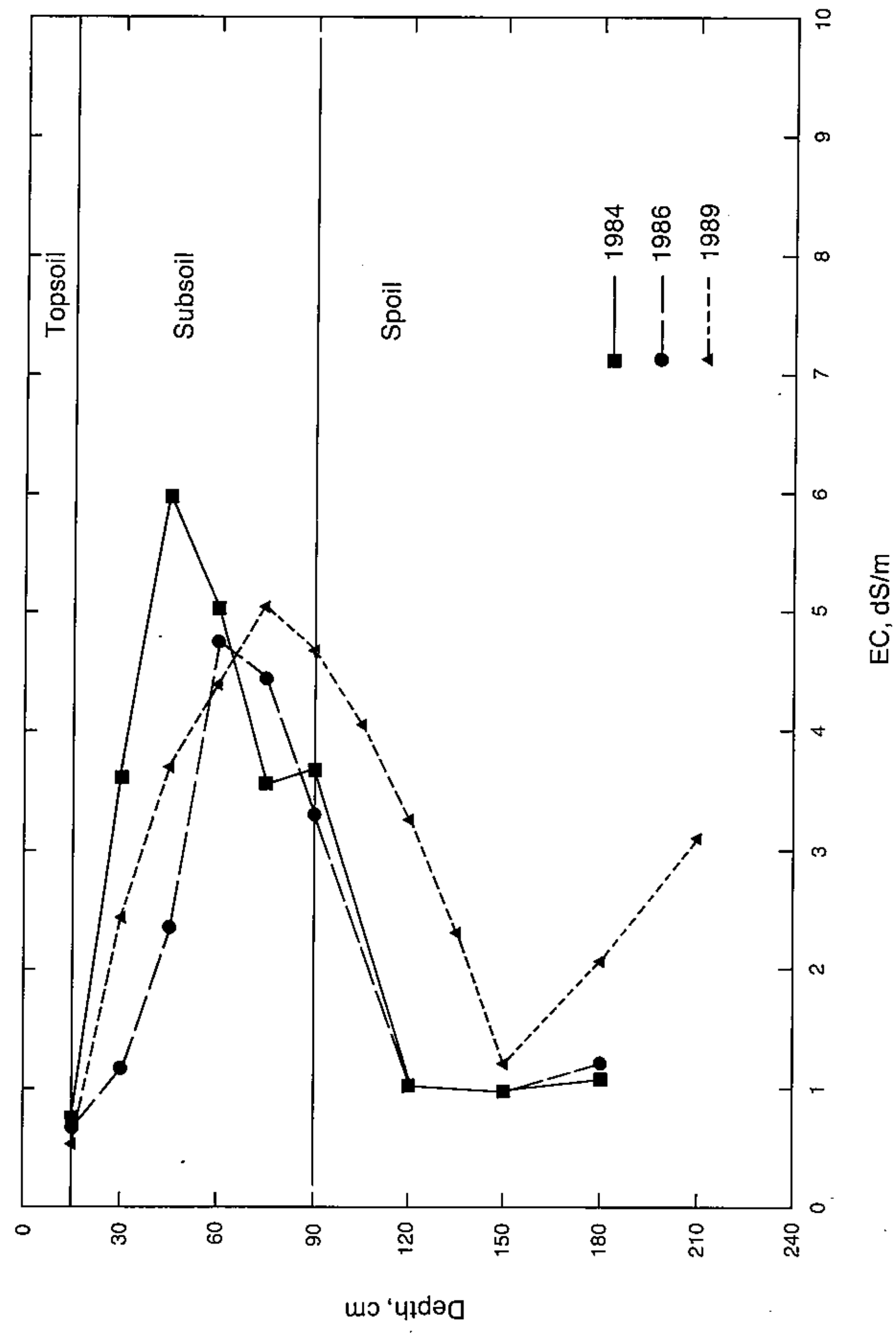

Figure 22. Mean EC values for Vesta site BR132 for the years 1984, 1986 and 1989.

mining landscape. In some areas of the United States, compaction is a major problem for achieving reclamation success (Jansen and Hooks 1988; McCormack 1987; Smout 1987).

In order to compare the influence of density on agricultural capability between reconstructed soils and unmined soils, a Density Capability Index (DCI) was developed. The DCI is a ratio of unmined soil density over reconstructed soil density for the upper 90 cm of the soil profile. Since there are several density readings in this interval, a weighting factor based on depth was used for each of the readings to determine its contribution to the density capability index (Table 4). The 15 cm interval (represented by measurement at 7.5 cm from the surface) was given a weighting factor of only 0.05 because of the inherent error in density values measured at this shallow a depth. To accommodate the inherent variability in density measurements, three values were used at each depth – mean, maximum, and minimum values – and another weighting factor was used to determine their contribution to the DCI (Table 4). Multiplying the weighting factors for depth and variability gave the overall weighting factor for each reading (Table 4). The density capability index (DCI) was calculated as expressed in the following equation:

$$DCI = \sum_{(d=0, v=\min)}^{(90,\max)} \frac{(\text{unmined soil density})_{(d,v)}}{(\text{reconstructed soil density})_{(d,v)}} * wf_{(d,v)}$$

where wf = overall weighting factor (for depth and variability),

d = depth of reading, and

v = variability of density reading (min, mean or max).

Table 5 illustrates the calculation of the Density Capability Index for reconstructed soils at Diplomat and Vesta Mines in comparison with unmined Heisler soils. We conclude from the index values that the only appreciably different density values between unmined and reconstructed profiles are between reconstructed soil at

Table 4. Weighting factors for depth and variability used in determining the Density Capability Index.

Depth of Reading		Depth Weight	Variability Weight	Overall Weight
15	max	0.05	0.3	0.015
	mean		0.6	0.030
	min		0.1	0.005
30	max	0.35	0.3	0.105
	mean		0.6	0.210
	min		0.1	0.035
45	max	0.25	0.3	0.075
	mean		0.6	0.150
	min		0.1	0.025
60	max	0.20	0.3	0.060
	mean		0.6	0.120
	min		0.1	0.020
75	max	0.10	0.3	0.030
	mean		0.6	0.060
	min		0.1	0.010
90	max	0.05	0.3	0.015
	mean		0.6	0.030
	min		0.1	0.005

Table 5. Calculation of Density Capability Index (DCI) for the unmined soil "Heisler" and Diplomat and Vesta reconstructed soils.

Depth (cm)		Overall Weight	← Heisler	Density (grams/cm³) Diplomat	→ Vesta	Heisler / Diplomat	Heisler / Vesta
15	max	0.015	1.15	1.84	1.80	0.009	0.010
	mean	0.030	1.12	1.72	1.52	0.020	0.022
	min	0.005	1.09	1.58	1.15	0.003	0.005
30	max	0.105	1.32	1.62	1.58	0.086	0.088
	mean	0.210	1.28	1.53	1.43	0.176	0.188
	min	0.035	1.25	1.37	1.12	0.032	0.039
45	max	0.075	1.55	1.71	1.76	0.068	0.066
	mean	0.150	1.46	1.68	1.61	0.130	0.136
	min	0.025	1.37	1.66	1.4	0.021	0.024
60	max	0.060	1.59	1.73	1.8	0.055	0.053
	mean	0.120	1.58	1.65	1.61	0.115	0.118
	min	0.020	1.56	1.53	1.28	0.020	0.024
75	max	0.030	1.67	1.75	1.79	0.029	0.028
	mean	0.060	1.67	1.68	1.61	0.060	0.062
	min	0.010	1.66	1.63	1.37	0.010	0.012
90	max	0.015	1.71	1.69	1.79	0.015	0.014
	mean	0.030	1.68	1.68	1.62	0.030	0.031
	min	0.005	1.65	1.67	1.34	0.005	0.006
					DCI:	0.884	0.927

Table 6. Density Capability Index values for reconstructed soil profiles in the Battle River area. Number in parentheses represents number of sites used in determination.

Unmined Soil Series	Reconstructed Soil: Diplomat (3)	Reconstructed Soil: Vesta (7)
Elnora (1)	0.964	N/A
Heisler (2)	0.884	0.927
Halkirk (2)	N/A	1.014

N/A - relationship (DCI) not applicable.

Diplomat Mine and unmined soil from the Heisler Series (Table 6). The DCI is within 10 percent for the other comparisons.

5.2.3 Differential Subsidence Decreases Capability

Differential subsidence forms depressions that are aligned between the original spoil ridges and appears to be an inevitable consequence of dragline mining (Dusseault et al. 1985). Newly placed and graded cast overburden, which is considerably less dense than the pre-mining overburden, has a loose structure with an initial secondary porosity of about 25 percent of the total volume. As water comes into contact with the spoil material, the structure of individual fragments collapses and the spoil quickly loses strength (Dusseault et al. 1988). Through this process, the entire spoil mass compacts, resulting in subsidence of the land surface (Dusseault et al. 1985). The majority of the subsidence occurs in the capillary fringe above the rising water table as the spoil resaturates (Figure 23). In addition to area-wide subsidence, which results in general lowering of the land surface, differential subsidence results in formation of numerous oval depressions about 10 m by 20 m and as much as 0.5 m deep. These depressions, which typically occupy from five to ten percent of the reclaimed surface, increase infiltration and accelerate differential subsidence by ponding water during spring melt and heavy summer rain storms.

5.2.4 Ephemeral Ponding Decreases Capability

Ephemeral ponding of water in depressions that form by differential subsidence of spoil decreases capability of a reclaimed landscape for agriculture in two ways: (1) ponding in the spring disrupts seeding, and during the summer it drowns crops (Figure 24); and (2) evaporation from the saturated soil around perched ponds in reclaimed landscapes has the potential to produce sodic, saline soils (Figure 25).

The ponding produced by spoil subsidence differs from the ponding that characterizes adjacent unmined landscapes in the number, size, and orientation of the

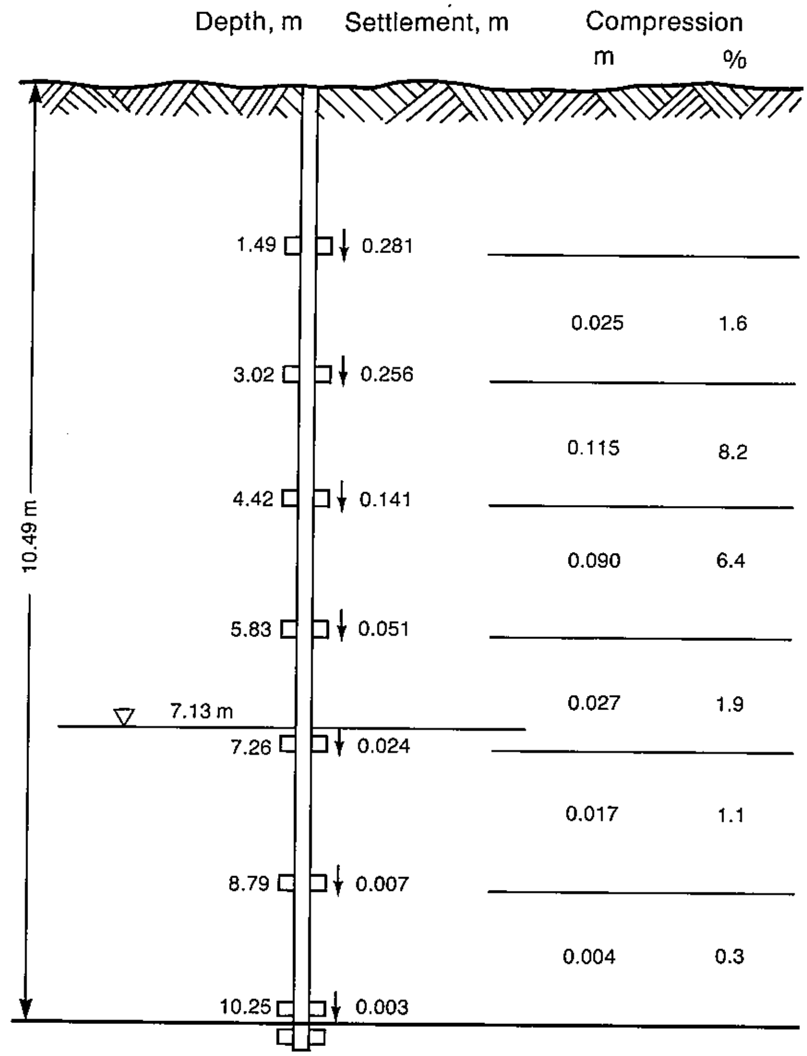

Figure 23. Multipoint extensometer at Diplomat Mine showing settlement within the spoil as a function of depth. The majority of settlement occurred between 3.0 and 4.5 m depth, within the zone of capillarity above the water table.

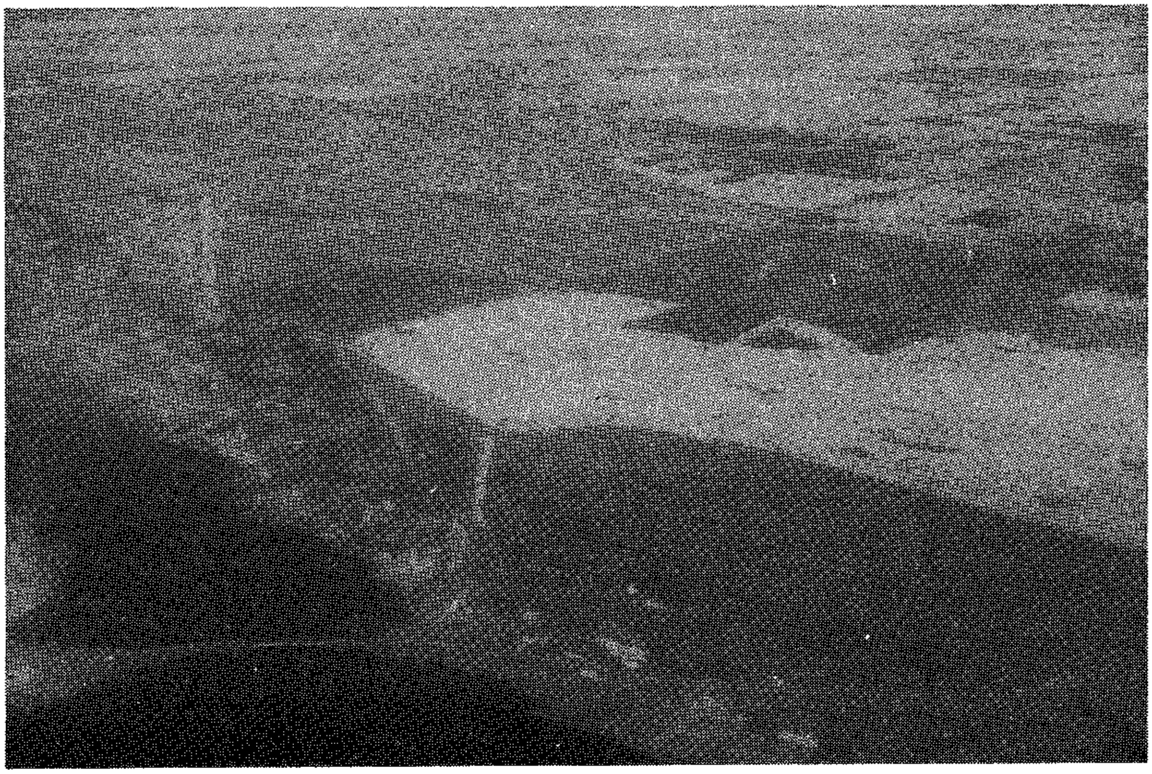

Figure 24. Aerial view of reclaimed spoil at Diplomat Mine showing crop damage from ponding.

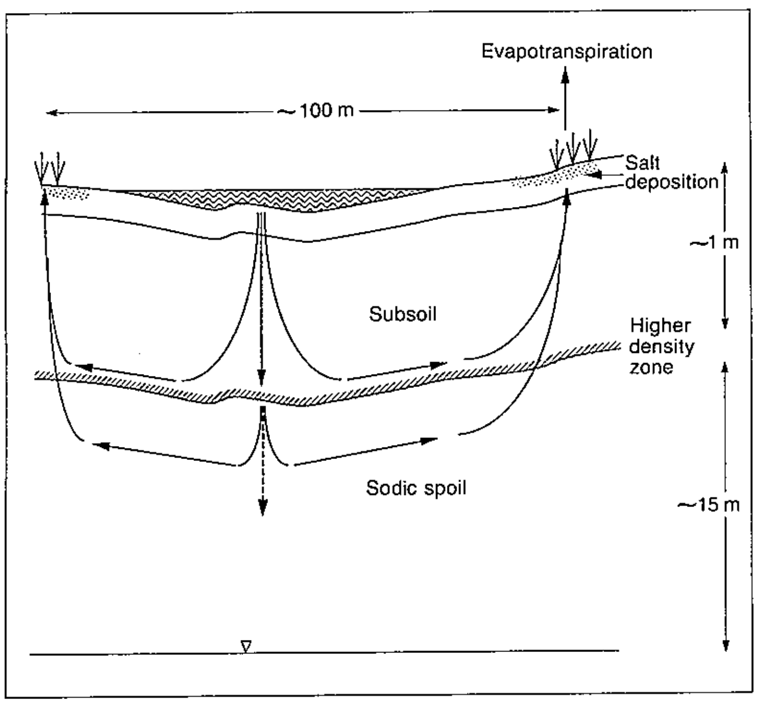

Figure 25. Schematic drawing showing the salinization mechanism at edge of perched ponds (After Moran et al. 1990).

ponded depressions. The reclaimed landscape contains numerous small depressions that are distributed in parallel lines across the entire quarter section, whereas the unmined undulating to rolling glacial terrain generally contains a small number of larger depressions per quarter. As a result, ephemeral ponding on reclaimed surfaces potentially results in greater disruption of field patterns, and in wet years, makes farming operations less efficient than on unmined land.

Perched ponds in reclaimed landscapes have the potential to produce sodic, saline soils. As indicated in Section 4.3, hydraulic conductivity of sodic, bedrock-derived spoil is at least two orders of magnitude lower than that of the drift-derived subsoil. This change in hydraulic conductivity acts as a barrier to the downward infiltration of water. As a result, water ponded in subsidence depressions is perched above the permanent water table in the spoil (Figure 25). Evaporation from the saturated soil surface and transpiration from plants around the edge of these depressions induces flow outward from the pond and upward from the upper surface of the spoil. Salt and sodium levels in the soil surrounding these depressions are expected to increase over time to levels that are detrimental to vegetation so that capability of these areas is permanently decreased.

5.3 POTENTIAL SALINIZATION OF RECLAIMED LANDSCAPES

Development of dryland salinity is a consequence of the interactions of three factors: (1) a source of salt; (2) climatic factors; and (3) hydrologic factors, which include the depth to the water table and the direction of groundwater flow. For soil salinity to occur, groundwater flow must be toward the soil surface. In reclaimed landscapes, soil salinity has been observed to form within a few years in lowland settings where extensive ponding of surface water develops. The way in which the three salinity development factors apply to the occurrence of salinity in reclaimed landscapes is discussed in this section of the report.

5.3.1 Salinization Factors

In the plains region of Alberta, sufficient salt is available within overburden materials to produce problem salinity almost everywhere that the necessary hydrologic and climatic conditions are met. Our studies indicate that, in most cases, the salt that is generated from the exposure of unweathered overburden to the atmosphere as a result of the mining process, is insignificant in comparison to the large reservoir of soluble salt already present in the overburden.

In order for salinization to develop, climatic conditions must favour its development, in particular, evaporation and evapotranspiration must exceed precipitation. Although the threshold climatic conditions necessary for salinity to develop are not well understood, it is evident that they are exceeded in most of the agricultural region of east-central and southern Alberta. Dryland salinity, although more of a problem in southern and southwestern regions, is of concern for potential surface mines throughout the grassland and parkland ecoregions of the province. As the presence of salt and climatic conditions appear to be ubiquitous, we conclude that the critical factors to be understood in coping with salinization of reclaimed landscapes are related to water and its movement, specifically to the dynamics of groundwater movement.

For dryland soil salinity to develop two hydrologic conditions must be met. The first requirement is that the water table persists within a certain critical depth range beneath the surface for an extended period during the growing season. The second requirement is that the net flux of groundwater over time is toward the site of potential salt accumulation. Specifically, salinity develops where groundwater flow is directed upward or laterally into an area where the water table lies within about 2.0 m of the surface. Because no existing or proposed surface coal mines in the plains of Alberta are known to lie in areas of regional groundwater discharge, we restrict our discussion to lateral flow of shallow groundwater. The principal mechanism by which shallow, lateral groundwater flow develops in reclaimed terrain is the presence of a barrier at depth, such as a marked decrease in hydraulic conductivity caused by a change in material. This condition occurs twice within reclaimed landscapes: (1) the hydraulic conductivity of the undisturbed rock beneath the pit floor is, in general, significantly lower than the overlying spoil; and (2) the hydraulic conductivity of till-derived subsoil is, in general, significantly greater than the underlying spoil, which is derived from sodic bedrock.

5.3.2 Salinization Model

Salinization is caused by removal of water from the capillary fringe above a shallow water table by direct evaporation and evapotranspiration through plants. The salt is left as a precipitate as the water is removed. It is evident that the equilibrium salt status of a given profile is the net result of competing rates of salt accumulation in response to evaporation and evapotranspiration, and of salt leaching in response to infiltration. We concluded that depth of the spring water table and the precipitation during the growing season can be used as indices of these two processes (Figure 26). Since the rate of upward transport of water and salt is greatest at shallow water table depths, it appears reasonable to consider the high spring water table position as an index of the relative strength of this upward component of flux that favours accumulation of salt. For a given material and landscape setting, the rate of leaching of salt is a function of precipitation. All other factors being equal, the tendency for salt to be leached from the profile increases with precipitation.

Based on individual yearly observations at a limited range of reclaimed sites, salt accumulated at the land surface where the water-table depth was less than about 0.6 m, regardless of the precipitation. Where the water table was deeper, however, the presence of a salt accumulation zone in the profile was strongly dependent on growing-season precipitation (Figure 26). This relationship can be expressed by the equation,

$$\text{Depth}_{\text{Critical}} = 2.9 - 7.1(\text{Pptn}),$$

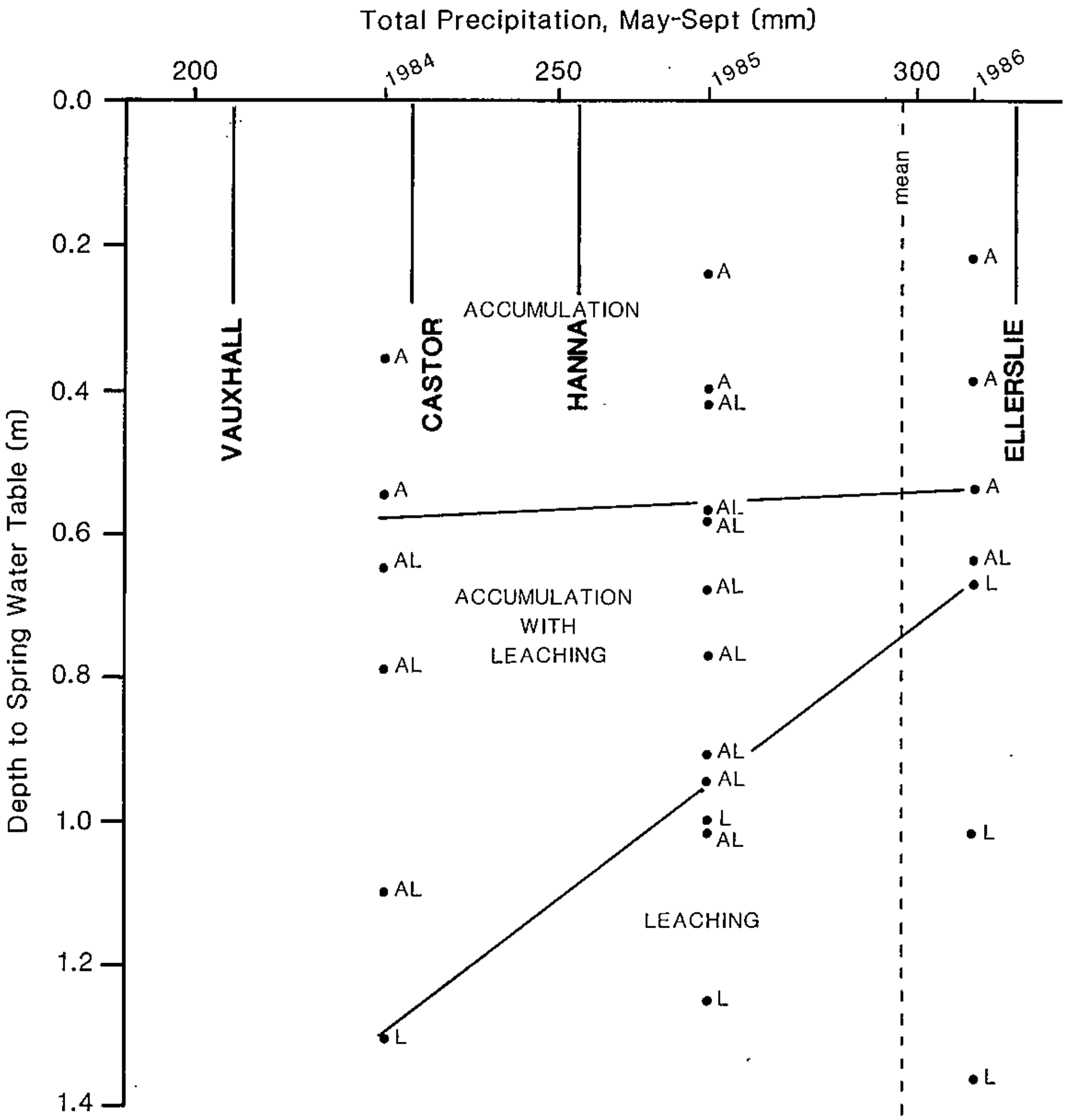

Figure 26. Depth of spring water table versus growing season precipitation, with mean growing season precipitation (based on 30 year normals) for selected Alberta locations indicated

where $Depth_{Critical}$ = water table depth at or above which accumulation of salts occurs within the profile, measured in metres; and

Pptn = growing season precipitation, also measured in metres.

It is reasonable to assume that the same approach could be extended to multiple sites using long-term mean precipitation data to derive similar conclusions regarding equilibrium salt profiles in an area, as suggested in Figure 26. This relationship could be used to predict salinization potential for other mine areas in the province.

5.3.3 Salinity Development in Reclaimed Landscapes

The salinity in reclaimed landscapes occurs in both upland and lowland settings. In lowland settings conditions favourable for the formation of soil salinity are common, and 20 to 30 percent of the land area may become either wet or saline. In upland settings salinity is a rare occurence. As discussed in Section 4.5, the hydrologic regimes in upland and lowland settings are fundamentally different. This difference has a bearing on the development of salinity in these two landscape settings.

5.3.3.1 Salinization in Lowland Reclaimed Settings. Salinity that has developed in the fringe area adjacent to a number of ponds in the lowland study site at Diplomat Mine (Figure 27) is interpreted to reflect discharge of groundwater flowing toward the pond from the upland to the southeast combined with groundwater flowing outward from the ponds themselves (Figure 28). The numerous depressions that dot the extensive upland to the east of these ponds provide appreciable recharge to the system. The shale and sandstone that comprise the pit floor beneath the spoil appear to be acting as a barrier to continued downward groundwater flow. Groundwater is thus forced to flow laterally toward the lowland area throughout the year. During spring melt and heavy rain storms, surface runoff augments direct precipitation in the lowland and the large lowland ponds become sites of recharge as well. The water table in the fringe area of the depression is

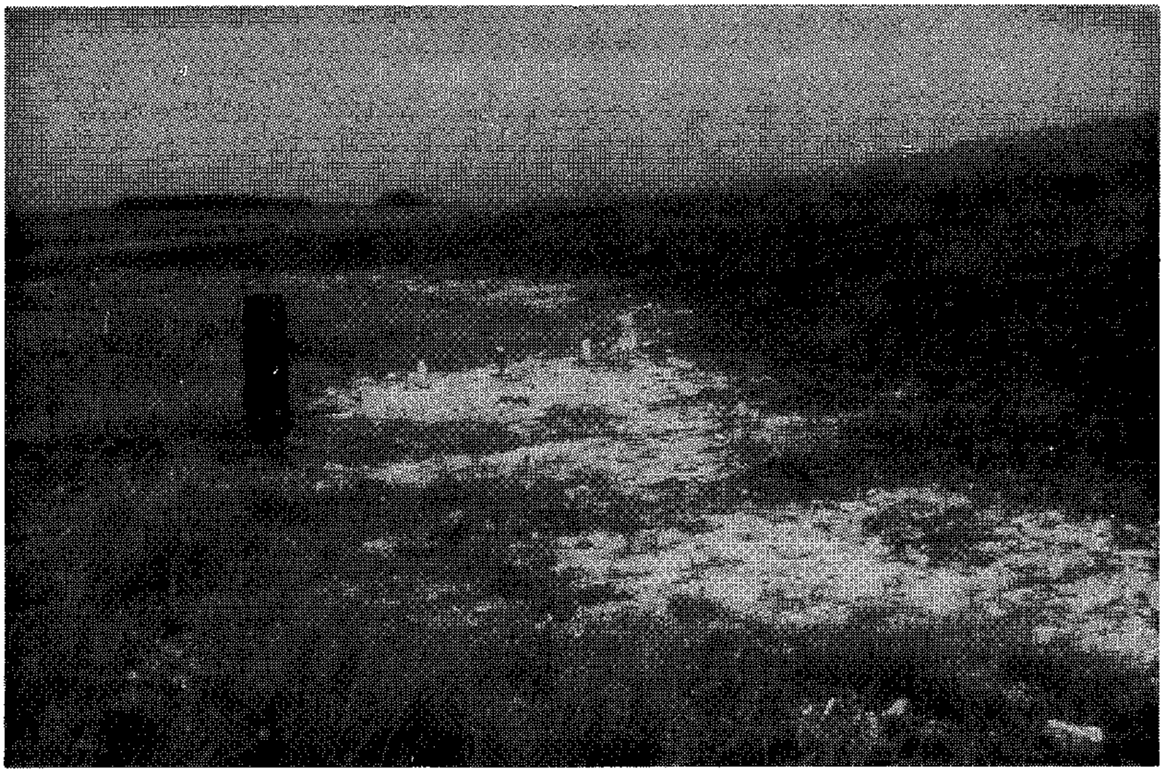

Figure 27 Pond in lowland setting at Diplomat Mine, showing salinity development in fringe area adjacent to the pond.

thus held within one to two metres of the surface throughout the growing season allowing formation of a saline fringe.

5.3.3.2 Salinization in Upland Reclaimed Settings. In rare cases where a depression is fed by sufficiently large drainage areas, and the subsoil or upper spoil has exceptionally low hydraulic conductivity, semi-permanent ponds can develop in upland areas. Surface salinity has been observed around the margins of one such pond in the reclaimed land at Vesta Mine (Figure 29). The formation of this salinity differs from the process in lowland settings in one important respect. The component of groundwater flow toward the site from beneath the adjacent upland is absent in the upland setting. The saline fringe results entirely from radial outward flow from the pond itself. The higher density of the subsoil and the upper surface of the sodic spoil appears to be acting as a barrier to rapid infiltration. Groundwater, which is perched above the water table, is forced to flow

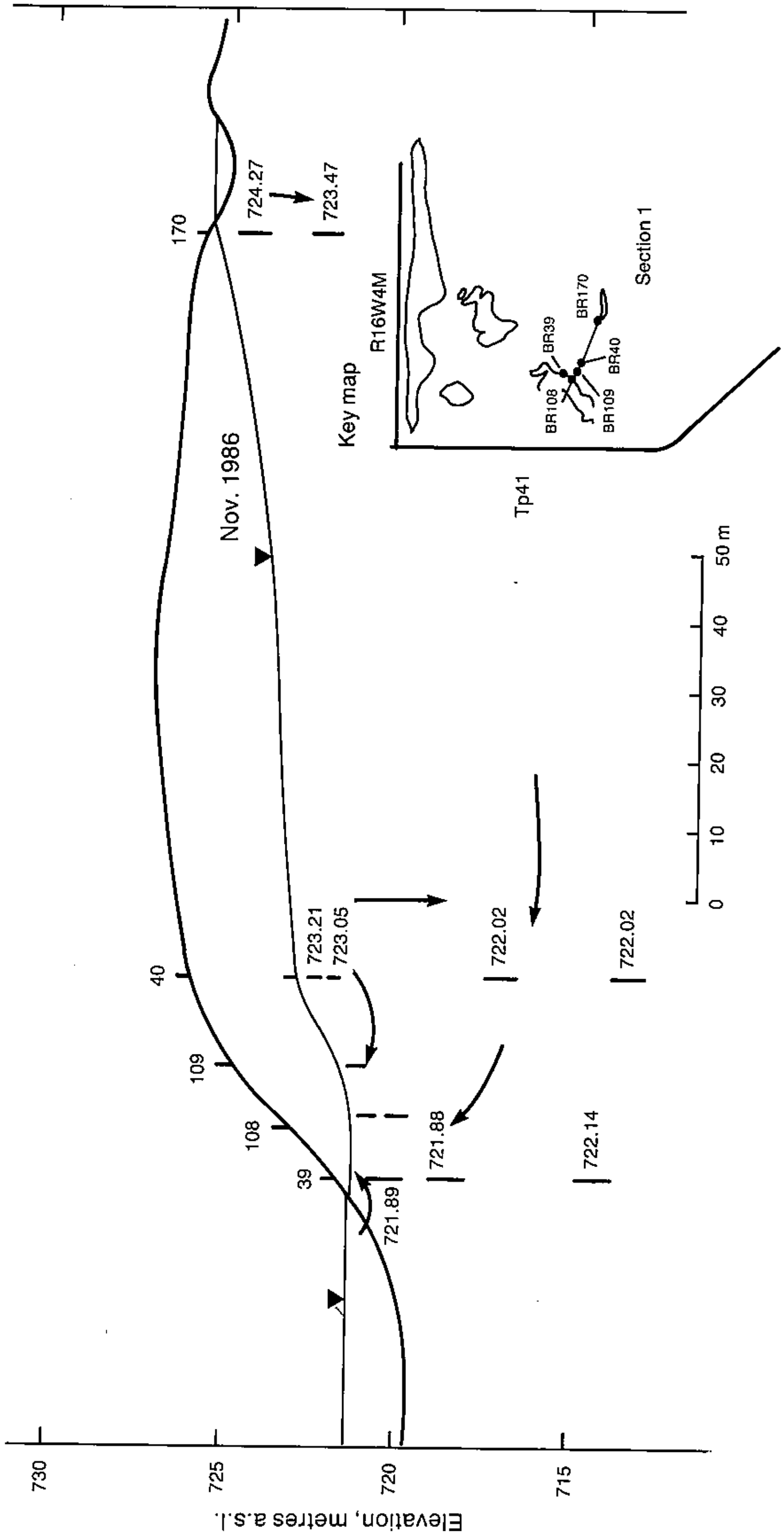

Figure 28. Cross-sectional view of pond and adjacent upland, reclaimed spoil at Diplomat Mine.

Figure 29. Pond in upland setting at Vesta Mine.

laterally from beneath the pond outward to discharge in the immediate vicinity of the pond, forming a saline fringe. The severity of salinity in this setting is not expected to be as great as in lowland settings because the total amount of salt available in upland settings is limited to the amount of salt in the subsoil beneath the pond; in lowland settings, salt is contributed from beneath the neighboring upland as well. In addition, these locations are groundwater recharge sites where the tendency is for salt to be redissolved from the saline fringe and carried downward. The initial precipitation of salt results only because the rate of recharge is very much slower than the rate at which water is supplied to the pond. In the restricted portion of upland settings around semi-permanent ponded upland depressions (less than 5 percent of the landscape), the salinity problem is expected to be exacerbated by sodium salts that are carried upward from the spoil and precipitated in the saline fringe.

5.3.4 Comparison with Unmined Sites

The principal unmined study site in the Battle River area, the Lunty Site, is located about 5.0 km east of the study site at Diplomat Mine (Figure 16). The terrain, geologic materials and hydrologic regime are analogous to the reclaimed landscape at Diplomat Mine. Specifically, the study site consists of undulating glacial stagnation moraine characterized by numerous pothole slough depressions (Figure 30). There is no integrated surface drainage on the site. Most of the depressions are ephemerally ponded, although ponding in the largest, lowest depression is semi-permanent. The glacial till varies in thickness from about three to ten metres. The underlying bedrock is the basal sandstone unit of the Horseshoe Canyon Formation. A permanent saline fringe occurs around a number of the low lying ponds.

The hydrogeologic regime of the unmined study site is summarized in Figure 31 by an east-west cross-section extending from the central slough towards the upland to the east. There is a component of groundwater flow directed from the upland toward the major depression. Where the water table lies within about 2.0 m of the surface in the marginal area of the slough, groundwater is removed by evapotranspiration and evaporation resulting in development of the saline fringe. During the spring, the saline fringe is fed by groundwater flow both from the upland and the pond.

The origin of the saline fringe in the lowland site at Diplomat appears to be analogous in every respect to the saline fringe around the large pond at the unmined site. The major difference between these two sites is in the severity of the salinity, both in terms of magnitude and distribution. The hydrologic similarities between the two sites leads us to conclude that the severity of salinity in the reclaimed site should, over time, approach that in the unmined site.

The TDS of groundwater beneath the saline fringe is 45 000 mg/L at the Lunty site, as compared with about 7000 mg/L at the reclaimed site. By simulating the evaporation of spoil groundwater using the chemical equilibrium model PHREEQE

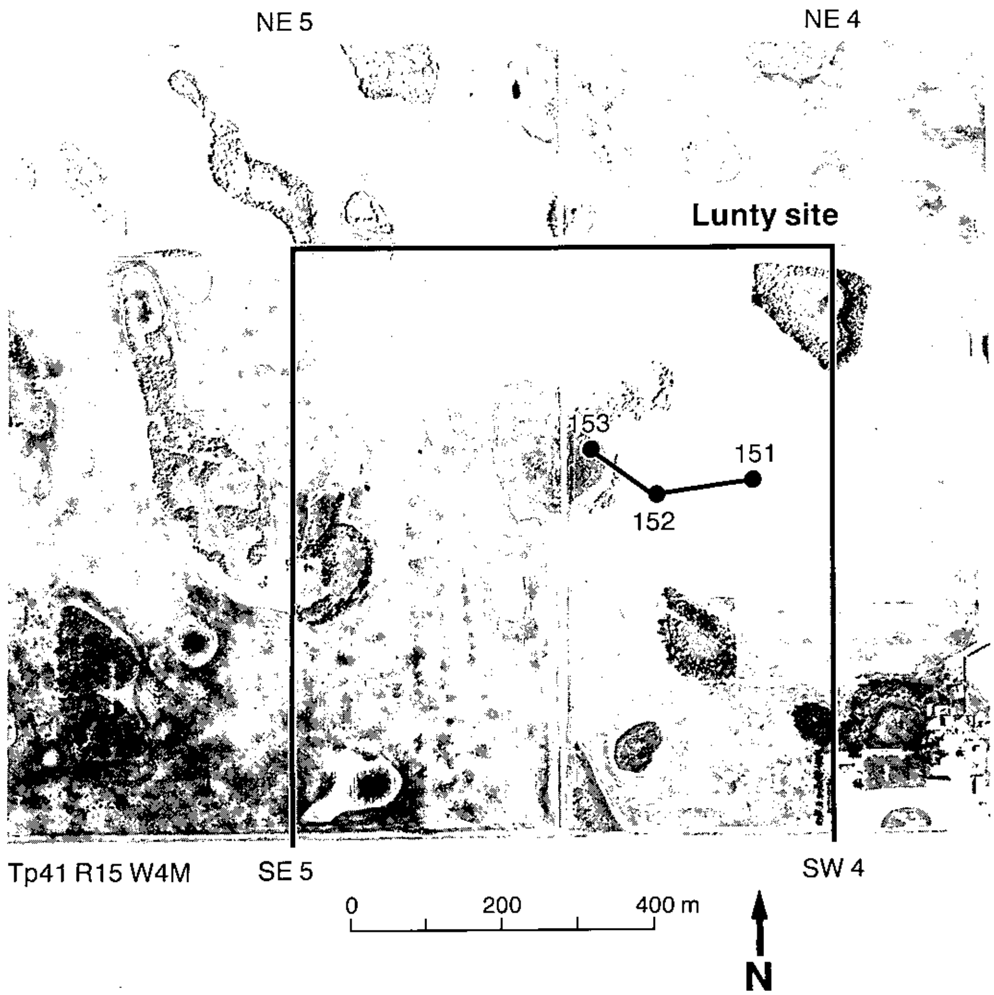

Figure 30. Air photo showing the unmined study site (Lunty) in the Battle River area.

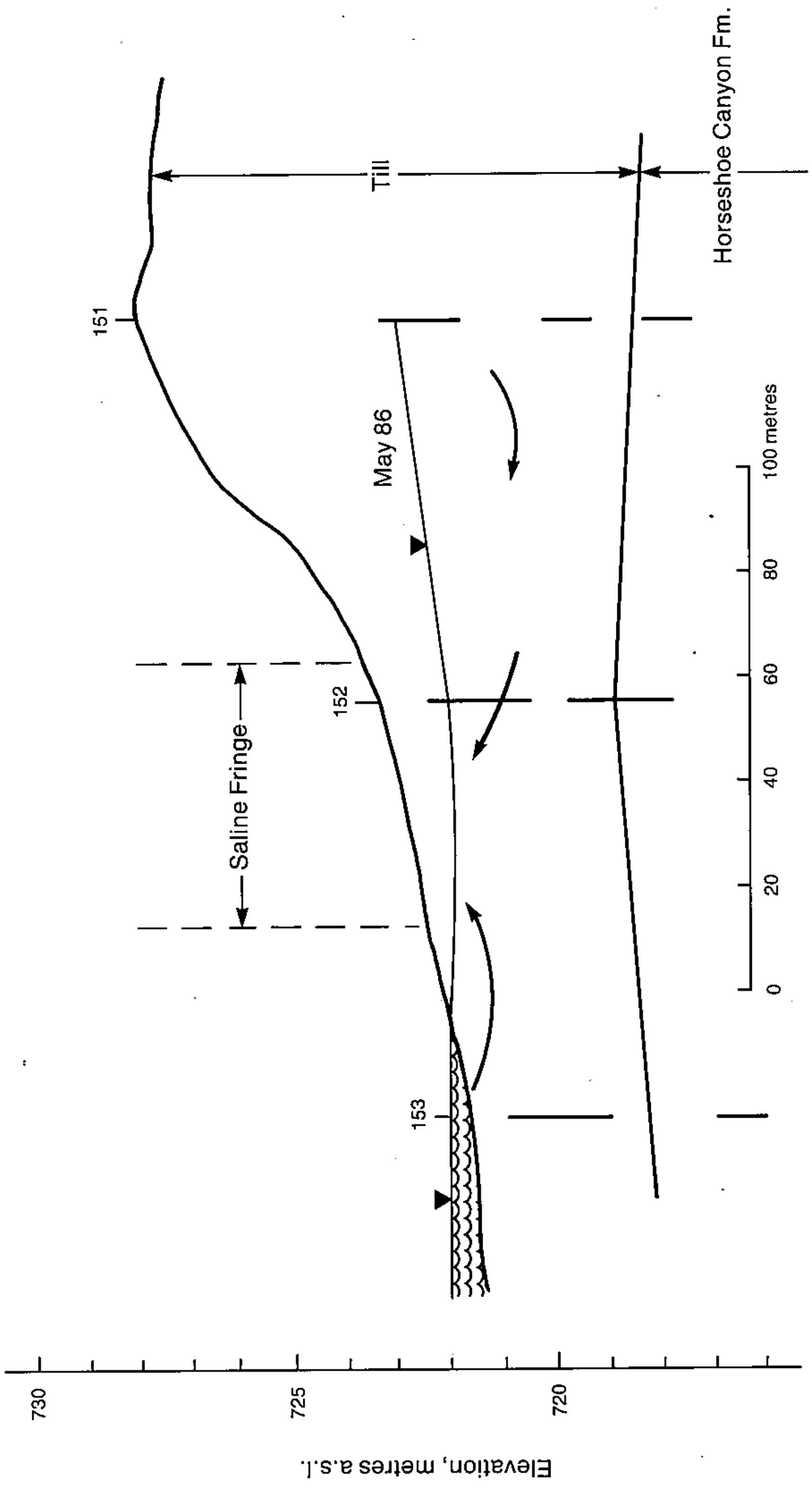

Figure 31. East-west cross-section of the unmined study site (Lunty).

(Parkhurst et al. 1980) we can approximate the minimum period of time required for this change in level of salinity (Moran et al. in prep). The mean salinity of the groundwater beneath the reclaimed site, 7000 mg/L, represents a concentration of about 1.3 times the background salinity of spoil groundwater at Diplomat Mine. If we assume that this increase in salinity developed over a period of about ten years, between completion of mining in 1974 and the initiation of our detailed study in 1984, and make the further assumption that the salinity develops progressively with time, we can estimate the time required for the salinity at Diplomat Mine to reach an equivalent level of severity as in the unmined site. From the data in our evaporation simulation (Figure 32), between two and three evaporative steps were required to reach the observed salinity at site BR39-A. This gives an average duration of about five years per step. Assuming that the process continues at the same rate, this suggests that approximately 45 or 50 years is required for the magnitude of the salinity at the reclaimed site to become as severe as at the unmined site.

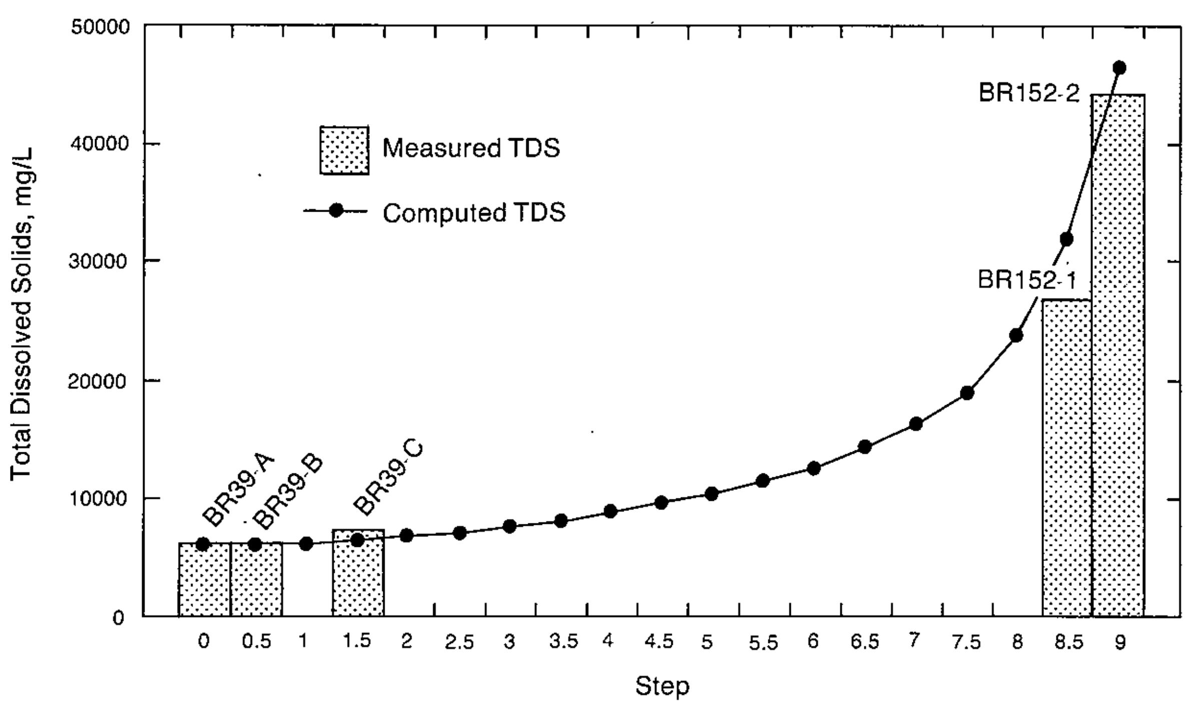

Figure 32. Evaporation simulation.

Saline soils are present where the depth to water table is as much as two metres at the unmined site compared to less than one metre at the Diplomat site. However, the observed accumulation of salts at the reclaimed site occurred over only a ten year time frame. One can expect that as time progresses that the distribution of salts in the reclaimed setting will extend into areas where the water table is as much as two metres in depth, as is observed in unmined settings.

6. IMPLICATIONS FOR RECLAMATION PRACTICE AND REGULATION

6.1 GROUNDWATER RESOURCES

The hydraulic properties of mine spoil in the plains of Alberta preclude development of water supplies above the base of disturbance within reclaimed mine sites. Cast overburden spoil has values of hydraulic conductivity that are considerably lower than those of the pre-mining coal aquifers, in the range of 10^{-7} to 10^{-9} m/s. At these values of hydraulic conductivity, the spoil is not capable of supplying water to wells. In addition, the major ion chemistry of groundwater in mine spoil was found to be considerably degraded relative to pre-mining aquifers. Mean Total Dissolved Solids values are generally 5000 to 7000 mg/L, and the water is generally saturated with respect to calcite, dolomite, and gypsum. At these concentrations, the water is unfit for consumption by both humans and livestock. The brackish nature of groundwater in mine spoil appears to be an inevitable consequence of mining in the plains region of Alberta.

There is no known method of materials handling that would alter either the hydraulic conductivity of mine spoil or the chemical make-up of the groundwater in mine spoil in this region. We conclude that disruption of shallow groundwater supplies within and above the coal is an unavoidable result of mining in the plains region. The only exception to this generalization would be where extensive, thick sand or gravel deposits lie on the bedrock surface or within the unconsolidated drift overburden. As indicated by Trudell and Moran (1986), it might be possible in such an instance to reconstruct a zone with significantly higher hydraulic conductivity by selectively handling and placing this sand or gravel. There is limited potential to replace the shallow groundwater supplies that are disturbed by mining. Deeper coal or sandstone aquifers that are capable of replacing the shallow coal aquifers removed by mining are present only in some areas. In places where the water quality in these aquifers is acceptable for human consumption, these aquifers offer the best option to replace water supplies lost as a result of mining. Alternatives to groundwater for domestic supply may include development of surface water supplies.

6.2 AGRICULTURAL RESOURCES

The impacts of mining on agricultural resources occur in two time frames: (1) immediate effects, and (2) progressive effects that have long-term implications. Immediate effects focus on the product of the soil reconstruction process. Materials handling associated with mining results in the mixing of the pre-existing soils to produce a reconstructed soil mantle of uniform thickness with properties that are an average of the pre-mining soils. Present requirements for the replacement of up to 1.5 m of subsoil material in addition to topsoil above sodic spoil appear to assure immediate post-reclamation capability that is comparable to that prior to mining. There is no evidence to suggest that replacement of greater thicknesses of buffer material would further improve capability.

Progressive effects focus on limitations and improvements to agriculture that develop over time; specifically, differential subsidence, which leads to ponding, soil salinization in lowland settings, and leaching in upland settings. Differential subsidence forms depressions that are aligned between the original spoil ridges, and appears to be an unavoidable consequence of dragline mining (Dusseault et al. 1985). These depressions, which typically occupy from five to ten percent of the reclaimed surface, increase infiltration and accelerate differential subsidence by ponding water during spring melt and heavy summer rain storms. As a result, cultivation patterns are disrupted, seeding and/or crop growth is restricted within the ponded depressions, and salinization may occur in the fringe area around the depression.

Salinization is a natural phenomenon whose conditions for formation are met in lowland reclaimed settings where ponding occurs, particularly if there is also ponding in the adjacent upland. Ponds in the lowland area cause the water table to persist near the surface. Where there is sufficient ponding in the upland to maintain the water table at levels above that in the adjacent lowland, groundwater will flow toward the lowland. In this setting, the fringe area around ponds in the lowland will become salinized. The flatter the landscape in the lowland, the larger the salinized area will be.

The impact of the negative progressive effects of mining and reclamation on agricultural resources can be minimized through modifications of materials placement and grading within existing operations. Grading as much of the upland portion of the reclaimed landscape as feasible into open slopes with integrated drainage can minimize ponding. Pauls et al. (in prep) report that slopes in the range of 1.5 to 3 percent along the long axis of subsidence depressions are sufficient to drain about 90 percent of the water that is ponded on existing reclaimed surfaces. Within the lowland areas, the extent of salinization can be minimized by grading to an undulating to rolling landscape with slopes of 3 percent to 5 percent. This will result in narrower zones around the lowland ponds where the water table is within the critical depth of the surface than when the terrain is more nearly level.

There is no known method to prevent the formation of lowland areas where overburden is thinner than the threshold value, other than the expensive process of transporting material from other areas in the mine. These lowland areas can be managed as productive hayland, pasture, or wildlife habitat, which adds much needed variety to the reclaimed landscape. In some cases, it may be desirable to design drainage measures into the materials handling system to facilitate management of the future lowland area.

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Trudell, M.R. and R. Faught, 1987. Premining groundwater conditions at the Highvale Mine site. Alberta Land Conservation and Reclamation Council Report #RRTAC 87-12. 83 pp.

Trudell, M.R. and S.R. Moran, 1986. Generalized procedures for assessing post-mining groundwater supply potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. Alberta Land Conservation and Reclamation Council Report #RRTAC 86-3. 30 pp.

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8. APPENDIX 1: PHRP LIST OF PUBLICATIONS

This publication list is by general subject headings as follows: Geochemistry, Geology, Geotechnical – Subsidence, Hydrogeology, Reclamation Impacts and Soils. A publication will only occur once in the list, however, if it covers more than one subject category, notation is made after the publication to that effect.

8.1 GEOCHEMISTRY

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Maslowski Schutze, A., 1986a. Geology of the Highvale site: Plains Hydrology and Reclamation Project. Alberta Land Conservation and Reclamation Council Report #RRTAC 87-11. 65 pp. and Appendices.

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