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                    Reclamation:  Key to Development of a Productive
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## ABSTRACT

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

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

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

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

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

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

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

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

## Introduction

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

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

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

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

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

## Geological Settings of Coal Resources in Interior Plains

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

final transgression, which occurred in the Paleocene Epoch about
60,000,000 years ago, extended only to the western edge of
North Dakota.

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

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

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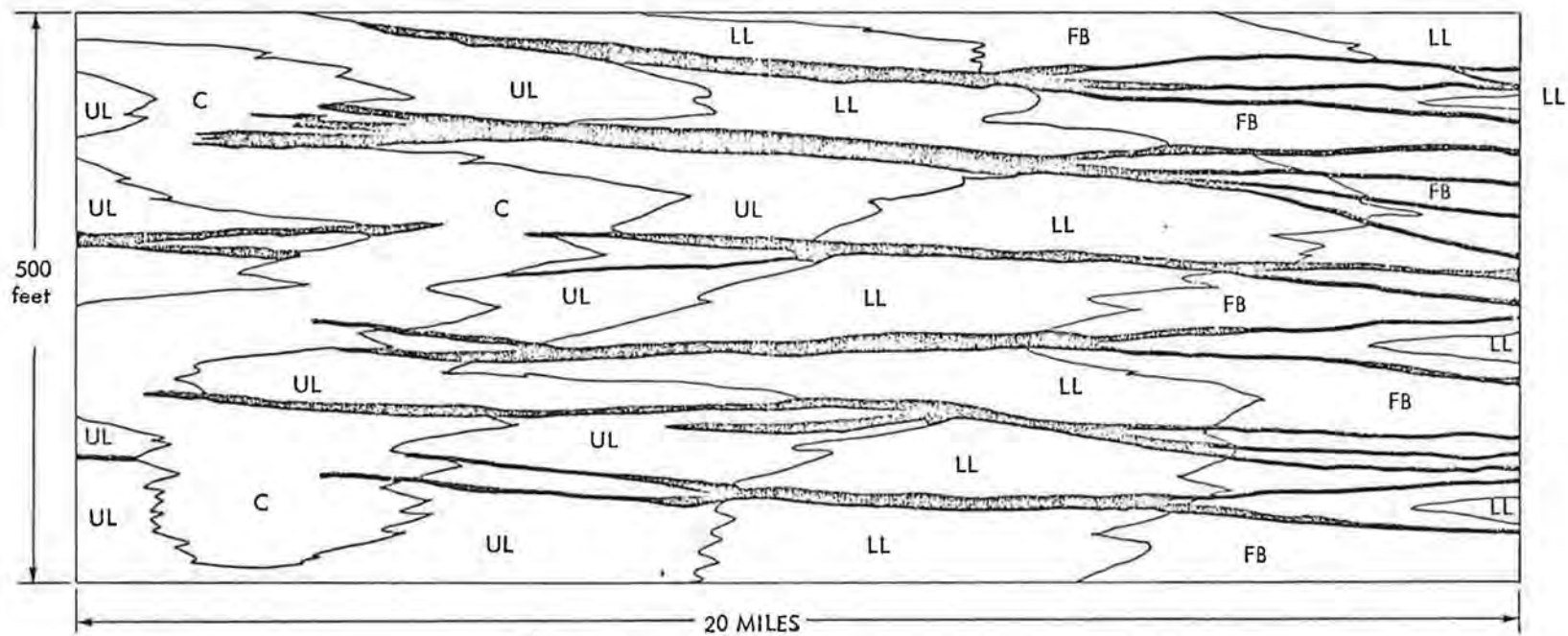(Fig. 1).

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

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

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

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

As a consequence of these environmental and sedimentological variations within the floodplain environment the original dis-tribution of mineral species varies.  The parent material from which most of the sediment was derived was early and middle Mesozoic and upper Paleozoic sedimentary rock.  Active volcanoes to the west provided a significant component of the sediment.  Carbonate minerals, dominantly calcite, are generally most abundant in the very fine sand and silt sizes.  Therefore, sediment of the channel and especially the levee contains calcareous material.  The finer grained sediment of the flood-basin generally contains less calcite.  Because of the fine grain size of the flood-basin sediment, clay minerals, generally montmorillonite, are most abundant here.  The origin of the sodium, which is the dominant exchangeable cation on the clay minerals in most areas, is not understood.  Possible sources include sodic volcanic debris, a significant minor constituent of the sediment, and sea water of later marine transgressions over the area.  Because of the generally reducing conditions of the flood-

basin environment, pyrite is more abundant in these sediments than
in the coarser grained sediment of the levee and channel, which
was deposited under generally oxidizing conditions. Because of the
continental setting and apparent humidity of the depositional
environment, it seems highly unlikely that any soluble salts were
deposited either as detritus or as precipitates from solution.

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

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

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

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

Hydrological Setting of Plains Area Coal Deposits

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

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

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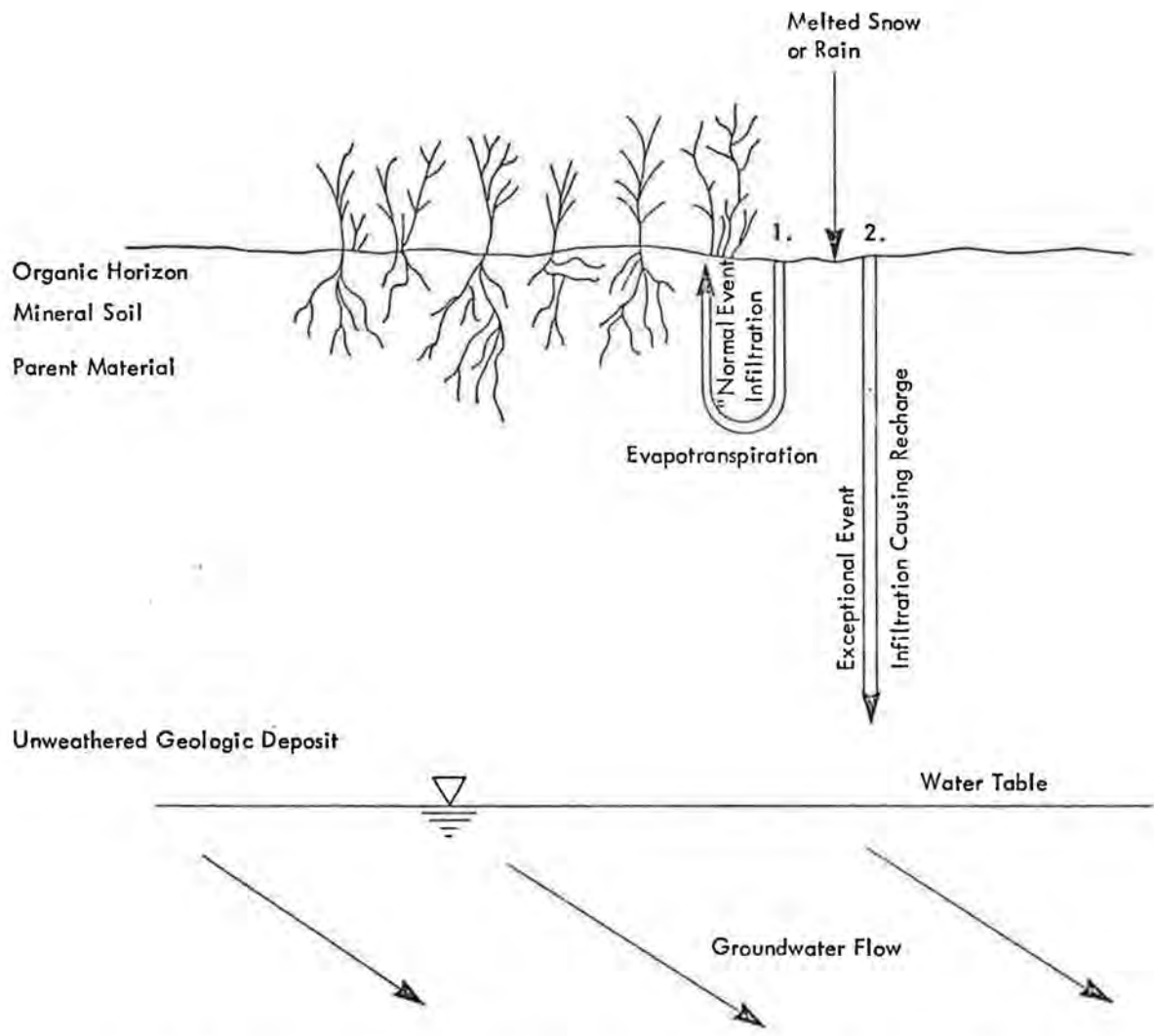
Melted Snow
or Rain

Organic Horizon

Mineral Soil

Parent Material

1.    2.

Normal Event
Infiltration

Evapotranspiration

Exceptional Event    Infiltration Causing Recharge

∞

Unweathered Geologic Deposit

▽                                                    Water Table

Groundwater Flow

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

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

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

We expect that the principal changes in the hydrologic regime that will be brought about by mining result from the more uniform distribution of hydraulic conductivity in cast overburden relative to the unmined condition. In many areas, the principal permeable beds prior to mining are the coal beds that are removed during mining. As a result, the more highly permeable, laterally continuous drains that can promote lateral flow will generally be absent in the mass of cast overburden. The silt and clay beds, which under natural conditions constitute the low permeability confining beds will be replaced as a blocky fill. The blocky structure of the clay, silt and shale material results in an increase in hydraulic conductivity as water is able to flow around the blocks rather than through the pores. The hydraulic conductivity of this clayey sediment probably decreases with time as the fractures are filled by fine-grained material produced by crushing of the blocky material and by slaking in response to wetting. The harder and more resistant the rock, the slower this process will operate.
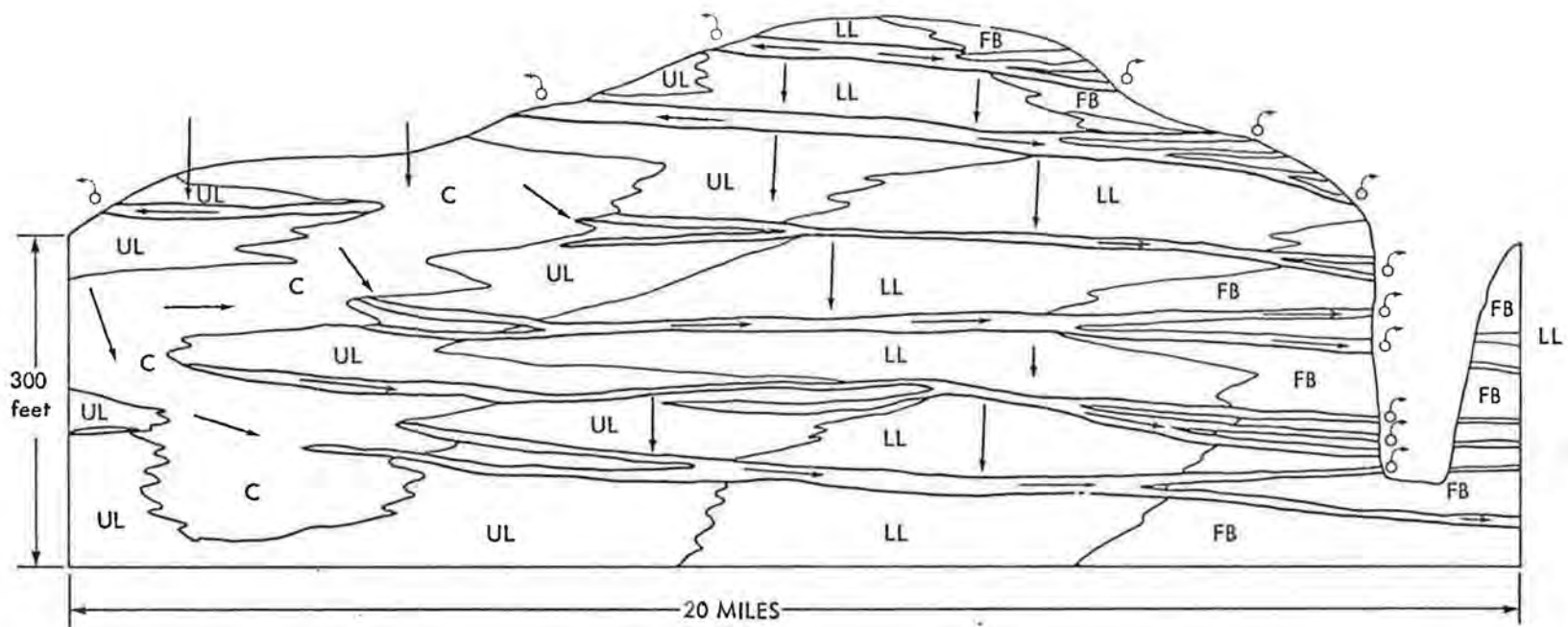
Figure 3.   Cross section showing typical pattern of groundwater
            flow in upland areas of the interior plains where
            glacial sediment is thin or absent.  Permeable coal
            beds channel groundwater flow laterally to springs
            and seeps at nearby outcrops.

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

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

## Hydrochemical Setting of Areas of Plains Coal Reserves

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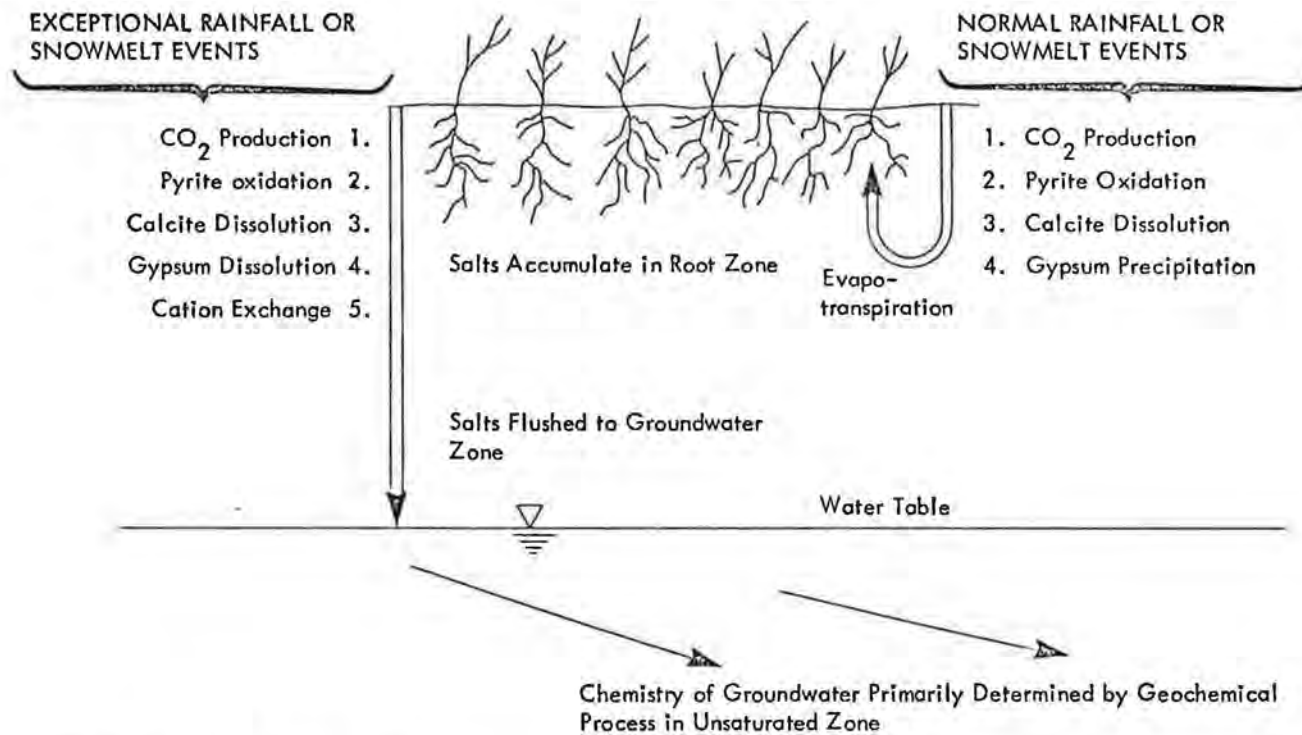
Fig. 4 : Schematic diagram of chemical processes and salt movement in much of the plains regions.

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

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

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

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

GEOCHEMICAL PROCESSES

1. $CO_2$ Production in Organic Soil Horizons Due to Oxidation of Organic Matter

2. Oxidation of Pyrite by Dissolved Oxygen

3. Dissolution of Calcite

4. Precipitation of Calcite & Gypsum Due to Evopo-Transpiration

1 — pH = 4.0 to 5.5, $H^+$ = dominant cation, $HCO_3^-$ = dominant anion, very low TDS

1 2 — pH = 2 to 4, $H^+$ = dominant cation, $SO_4^{2-}$ = dominant anion, low TDS

1 2 3 — pH = 7 to 8, Ca – $HCO_3$ type water, moderate TDS

1 2 3 4 — high TDS, high $Ca^{2+}$, $HCO_3^-$ and $SO_4^{2-}$ as concentration occurs
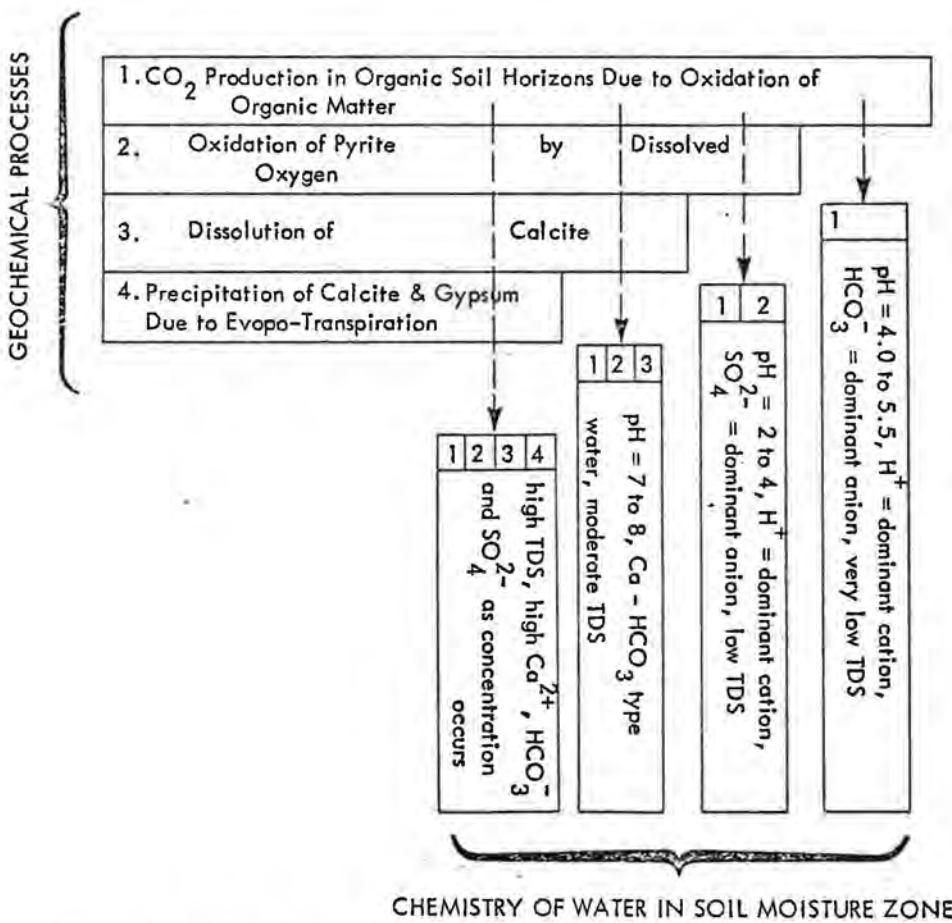
CHEMISTRY OF WATER IN SOIL MOISTURE ZONE

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

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

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

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

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

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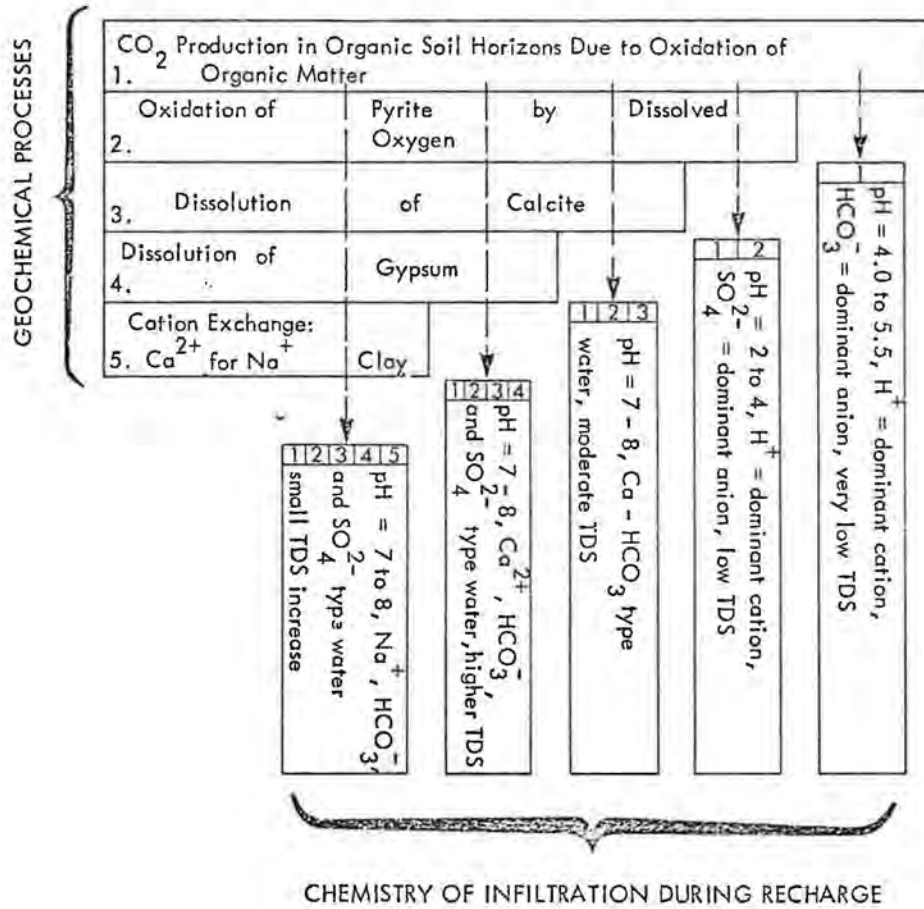
CHEMISTRY OF INFILTRATION DURING RECHARGE

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

## Some Concepts for Mineland Reclamation

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

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

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

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

These objectives can both be achieved if moderately permeable sandy materials are placed as a layer at the upper part of the cast overburden beneath a veneer of plant growth material (soil and subsoil). The most desirable sand for this purpose is well sorted channel sand, which has low clay and silt content and therefore higher permeability and lower exchangeable Na than the other types of bedrock sediment that occur above the exploitable coal. Based on the interpretive geochemical framework outlined above, emplacement of a few metres of permeable sand

beneath the soil veneer would prevent the formation of appreciable amounts of $SO_4^{2-}$ in soil and subsoil water. If $SO_4^{2-}$ production by pyrite oxidation is relatively inactive, and if infiltration passes through the sandy subsoil zone sufficiently frequently to prevent accumulation of gypsum from the small amount of $SO_4^{2-}$ that does occur, the pore water in the soil will be characterized by low dissolved solids. The water will have $HCO_3^-$ as the dominant anion, and will have low contents of $Na^+$, $Ca^{2+}$, and $Mg^{2+}$. Flushing as a result of snowmelt and heavy rainfall will gradually remove exchangeable sodium from the sand, leaving the exchange sites on the clays loaded with $Ca^{2+}$ generated mainly by the dissolution of carbonate materials.

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

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

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

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

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

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

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

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

In the climatic setting of western North Dakota, passage of rainfall or snowmelt through the sand will probably be infrequent if the sand is at least a few metres thick and if grass or crops that stimulate evapotranspiration are established. If irrigation were to be practiced, careful water management would be necessary to prevent excessive groundwater recharge. If the permeability contrast between the sandy subsoil sayer and the underlying deposit is appreciable, lateral flow in a saturated zone in the lower part of the sand will be the main mechanism of water flow from the sand if there is a sufficient slope in the water table. Construction of the cast overburden in a manner that will produce sufficient lateral groundwater runoff in the event that excessive infiltration through the root zone occurs would be a necessary

objective in the mineland reclamation program. The groundwater zone developed at the base of the sand would be in a perched water-table condition during at least the first few years or decades of the 'wetting up' phase of adjustment of the cast over-burden to the hydrologic conditions. Eventually the finer-grained deposits below the more permeable deposits would become saturated.

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

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

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

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

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

What is much less certain, however, would be the concentrations of trace metals that would develop in the aquifer water. Since little is known about the occurrence of and geochemical controls on trace metals in the natural groundwater in the region, there is no interpretive framework available upon which to base predictions. There is some possibility that the materials in the cast overburden, while under natural conditions, contain groundwater with acceptable concentrations

of trace elements, will release higher concentrations of these metals to
water in the cast overburden as the water encounters surface areas that
were previously not well exposed to circulating water.  Field studies
of the chemistry of groundwater in cast overburden that are currently
in progress at several sites in western North Dakota, should shed
some light on the geochemistry of trace elements in these materials.

Summary of Conclusions

1.   With existing methods of field investigation, the spatial
     distribution of the various types of geologic materials in the areas
     of actual or potential coal mining in western North Dakota are being
     successfully defined in detail.  This process proceeds most efficiently
     when a conceptual framework based on interpretations of the original
     depositional environments of the sediments is used as a basis for the
     designs of drilling and sampling programs.

2.   Studies of the groundwater conditions in areas of actual or potential
     mining and studies of soil moisture conditions elsewhere in the region
     indicate that nearly all of the water from rain and snow that penetrates
     the ground surface does not infiltrate below the root zone.  This
     water is lost by evapotranspiration.  Groundwater recharge is
     infrequent and generally occurs most significantly in local topo-
     graphic depressions.  The fact that water frequently penetrates into
     the soil and shallow subsoil but rarely passes through it is a key
     factor in the development of salinity in the soil and in the under-
     lying groundwater zone.

3.   Studies of the chemistry of groundwater in areas of actual or
     potential mining indicate that the salts that occur in the natural
     groundwater are derived almost entirely by geochemical processes that
     are active in the soil and in the subsoil zone above the bottom
     limit of the root zone.  That is, the water acquires its salts in
     the upper few metres of the hydrologic system.  This is the case
     even though the subsurface water flows much farther and resides much
     longer in the groundwater zone located well below this shallow zone
     of geochemical activity.

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

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

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

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

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

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

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# PROCEEDINGS

OF

## THE SECOND ANNUAL GENERAL MEETING

### OF THE

## CANADIAN LAND RECLAMATION ASSOCIATION

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

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

P R O G R A M

Canadian Land Reclamation Association

Second Annual General Meeting

August 17, 18, 19, 20, 1977

Edmonton, Alberta


Wednesday, August 17 (Optional Field Trips)


Field Trip No. 1   (Athabasca Tar Sands)

   Leader:   Philip Lulman (Syncrude Canada Ltd.)

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

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

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

   Leader:   George Robbins (Luscar Ltd.)

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

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

## Thursday, August 18

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

1:25 p.m.      Continuation of Paper Presentations.  Afternoon
               session chaired by Mr. Philip Lulman (member of
               C.L.R.A. executive; reclamation research ecologist
               with Syncrude Canada Ltd.).

1:30 p.m.      Paper 5. Coal Mine Spoils and Their Revegetation
               Patterns in Central Alberta by A.E.A. Schumacher,
               R. Hermesh and A.L. Bedwany (presented by Alex
               Schumacher of Montreal Engineering Company Ltd.,
               Calgary, Alberta).

2:00 p.m.      Paper 6. Surface Reclamation Situations and Practices
               on Coal Exploration and Surface Mine Sites at
               Sparwood, B.C. by R.J. Berdusco and A.W. Milligan
               (presented by Roger Berdusco of Kaiser Resources
               Ltd., Sparwood, B.C.).

2:30 p.m.      Paper 7. Agronomic Properties and Reclamation
               Possibilities for Surface Materials on Syncrude
               Lease #17 by H.M. Etter and G.L. Lesko (presented
               by Harold Etter of Thurber Consultants Ltd.,
               Victoria, B.C.).

3:00 p.m.      Paper 8. The Use of Peat, Fertilizers and Mine
               Overburden to Stabilize Steep Tailings Sand Slopes
               by Michael J. Rowell of Norwest Soils Research
               Ltd., Edmonton, Alberta.

3:30 p.m.      Coffee Recess

4:00 p.m.      Paper 9. Oil Sands Tailings; Integrated Planning to
               Provide Long-Term Stabilization by David W. Devenny
               of E.B.A. Engineering Consultants Ltd., Edmonton,
               Alberta.

4:30 p.m.      Paper 10. Bioengineering.  The Use of Plant Biomass to
               Stabilize and Reclaim Highly Disturbed Sites by
               H. Schiechtel an, sK. (Nick) Horstmann (presented by
               Margit Kuttler).

5:00 p.m.      End of August 18 Sessions.

Events:       Presentation of Papers; C.L.R.A. Annual General Business Meeting; C.L.R.A. Annual Dinner.

Locations:     Paper presentations and C.L.R.A. Annual General Business Meeting in Multi-Media Room, located on second floor of Education Building, University of Alberta.
- Annual Dinner held in Banquet Room located on second floor of Lister Hall.

8:00 a.m.     Authors of Papers being presented on August 19 meet with paper presentation chairmen and audio-visual co-ordinator (Douglas Patching).

8:30 a.m.     Showing of Film Rye on the Rocks. This film depicts reclamation situations at Copper Cliff, Ontario and is being shown for the purpose of introducing delegates to the site of the 1978 C.L.R.A. meeting (Sudbury, Ontario).

8:55 a.m.     Continuation of Paper Presentations. Morning session chaired by Dr. J.V. Thirgood (Vice-President of C.L.R.A.; member of Forestry Faculty, University of British Columbia).

9:00 a.m.     Paper 11. Reclamation of Coal Refuse Material on an Abandoned Mine Site at Staunton, Illinois by M.L. Wilkey and S.D. Zellmer (presented by Michael Wilkey of the Argonne National Laboratory, Argonne, Illinois).

9:30 a.m.     Paper 12. A Case Study of Materials and Techniques Used in the Rehabilitation of a Pit and a Quarry in Southern Ontario by Sherry E. Yundt of the Ontario Ministry of Natural Resources, Toronto, Ontario).

10:00 a.m.    Coffee Recess.

10:30 a.m.    Paper 13. Amelioration and Revegetation of Smelter-Contaminated Soils in the Coeur D'Alene Mining District of Northern Idaho by D.B. Carter, H. Loewenstein and F.H. Pitkin (presented by Daniel Carter of Technicolor Graphic Services Inc., Sioux Falls, South Dakota).

11:00 a.m.    Paper 14. The Influence of Uranium Mine Tailings on Tree Growth at Elliot Lake, Ontario by David R. Murray of the Elliot Lake Laboratory, Elliot Lake, Ontario.

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

12:00 noon      Lunch Recess.

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

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

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

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

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

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

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

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

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

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