GROUNDWATER HYDROLOGY AND GROUNDWATER-SURFACE WATER INTERACTIONS IN RECLAIMED LANDSCAPES IN EAST-CENTRAL ALBERTA, CANADA[1]

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Abstract.--Studies in east-central Alberta show relatively rapid establishment of a stable groundwater regime in terrain that has been reclaimed following surface mining. The pattern of resaturation is consistent with projections made by numerical modeling, but the observed rates of resaturation are significantly more rapid than projected. At early times in the resaturation process, lateral flow from unmined aquifers and especially from deep ponds that extend to the base of the spoil is a major process. Downward leakage from both permanent and ephemeral ponds, which is also important initially, becomes dominant as the groundwater level rises and gradients are reduced. The majority of our data have been developed where 5 to 10% of the land surface is covered by permanent ponds with another 3 to 5% cover by ephemeral ponds. In these settings, approximately 12 to 15 years are required to achieve nearly total recovery to a steady-state groundwater regime. On the basis of very limited data, resaturation in areas lacking permanent ponds appears to proceed at a much slower rate. At Diplomat Mine, which has reached the most nearly steady-state hydrologic regime, the water table is at or near the land surface beneath ponds and generally at a depth of several metres beneath intervening higher land. Where the water table is within 2.5 m of the surface, it responds very quickly to precipitation events and spring melt. This timing and the large magnitude of fluctuations in the water table are taken to indicate direct recharge. Where the water table is at greater depths, fluctuations are generally of smaller magnitude and tend to lag behind recharge events by several months. These characteristics are taken as indications that lateral flow from adjacent recharge areas is the primary mechanism of water level change in these locations.

In low lying areas, where the water table is within about a metre of the surface, significant levels of salt accumulation are observed. In such areas, groundwater discharge is already contributing to a progressive deterioration of the productive capability of reclaimed soils.

INTRODUCTION

Studies of five mine sites in the plains of east-central Alberta, which began in 1979, have provided insight into (1) the processes by which a stable groundwater regime is reestablished within reclaimed landscapes; (2) the steady state, post-mining water-table position and hydrologic regime; and (3) the hydrologic role played by various types of surface water bodies in reclaimed landscapes. Three of the mines, Diplomat, Vesta, and Paintearth, are in the Battle River mining area (fig. 1), at the transition between the Black (Udic Boroll) and Dark Brown (Typic Boroll) Soil Zones. Hydrologic conditions here are more likely typical of mines in the Black Soil Zone. The other two mines, Highvale and Whitewood, are in the Wabamun mining area (fig. 1), which is in the Luvisolic (Boralf) Soil Zone. In parts of Whitewood, Highvale, Vesta, and Diplomat Mines,

[1]Paper presented at the combined Fourth Biennial Billings Symposium on Mining and Reclamation in the West and the National Meeting of the American Society for Surface Mining and Reclamation. March 17-19, 1987. Billings, MT.

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Proceedings America Society of Mining and Reclamation, 1987 pp 145-154
DOI: 10.21000/JASMR87010145

https://doi.org/10.21000/JASMR87010145

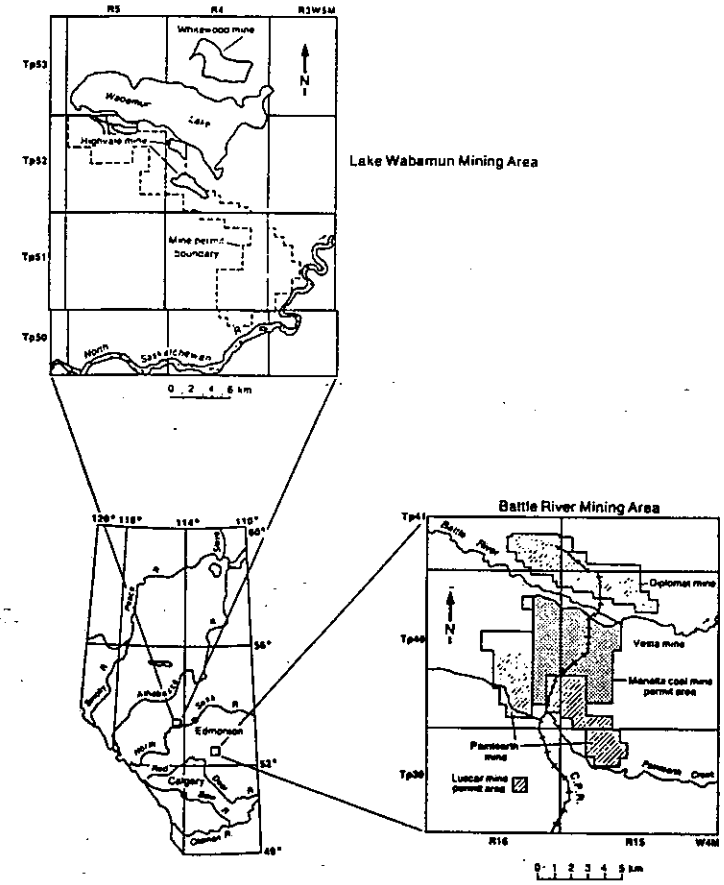

Figure 1.--Location of study sites east-central Alberta

the hydrologic regime appears to have nearly achieved a post-mining equilibrium. Elsewhere in these mines and at Paintearth Mine, stable hydrologic conditions have not yet been established.

RESATURATION OF RECLAIMED LANDSCAPES

During the mining process, overburden material is broken into fragments of various sizes that are replaced as spoil. The spaces between individual fragments create a secondary porosity that is numerically equivalent to the bulking factor associated with the conversion from overburden to spoil, and which is expressed in the elevated land surface in mined areas as well as the lower density of spoil relative to unmined overburden. Depending on the type of material involved and its initial water content, this secondary porosity can range from 10 to 30%. Initially, most of these pores contain air. Over time, the air in these pores is replaced by water as the spoil resaturates.

Sequence of Spoil Resaturation

Data from the instrumented sites confirms the general pattern of resaturation of spoil that is suggested by numerical modeling (Schwartz and Crowe 1984, 1985, in press). In the early stages of spoil resaturation, strong downward hydraulic gradients are expected to dominate as leakage from ponds and distributed upland infiltration contribute recharge to the spoil (fig. 2). At this stage, ponds in topographically low areas are water-table mounds contributing leakage to the groundwater system. As the water table in the spoil rises, reaching and then surpassing the elevation of the low-lying ponds, the hydraulic gradients beneath the lowland ponds reverse to become upward-directed, at least during part of the year (fig. 2). At Diplomat Mine, it appears that the spoil is approaching this stage with the onset of more frequently upward-directed vertical hydraulic gradients beneath lowland ponds. Where recharge in upland areas is strong enough, the water table will continue to rise beneath the upland generating significant lateral transport of water and salt from the higher areas toward the lower areas (fig. 2).

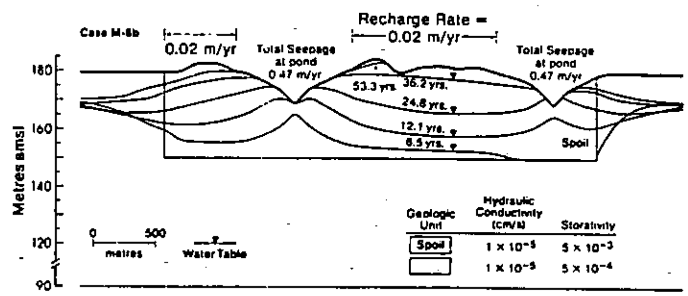

Figure 2.--Example of simulated water-level recovery in spoil, after Schwartz and Crowe (in press)

Process of Spoil Resaturation

Three main processes are involved in the resaturation of mine spoil:

- lateral flow from unmined aquifers and from previously resaturated spoil;
- lateral leakage from deep ponds;
- downward seepage from shallow ponds.

The relative importance of these processes varies with the setting of an individual mine and the stage in the resaturation process.

Resaturation by Lateral Flow from Unmined Aquifers

In the early stages of spoil resaturation, lateral inflow from adjacent unmined aquifers is a significant process at many mine sites because of the large hydraulic gradient. As the water table in the spoil rises, this source of water decreases. In some places, in the later stages of resaturation, water level in spoil is raised above the level in unmined aquifers by recharge within the reclaimed terrain, and flow is reversed with water flowing out of the spoil into adjacent aquifers (Trudell and Moran 1984).

The presence of lateral flow into mine spoil from adjacent unmined aquifers is shown by the distribution of hydraulic head data at the base of the spoil at three of the five mines studied. At Diplomat Mine, the hydraulic head in the coal north of the instrumented reclaimed area is higher than in the spoil during much of the year, indicating flow into the spoil. At Highvale Mine, the water table in the overburden sandstone beneath a hill adjacent to the west edge of Pit 01 is approximately 15 m above the water table in the spoil. It is likely that some resaturation of the spoil is resulting from lateral inflow of groundwater from the unmined overburden to the west of Pit 01. At the Whitewood Mine, the potentiometric surface at the base of the spoil indicates lateral flow from the unmined coal to the north into the spoil (Alberta Environment 1980, p. 54, 57).

Lateral Seepage from Deep Ponds

In places where ponds extend deep into the spoil, water moves laterally from the ponds into the spoil. Such a situation occurs with the deep final cut pond at the north end of the instrumented site at Diplomat Mine (S-7), and with the large deep pond at the north edge of the instrumented site at Vesta Mine (S-20).

At pond S-7 in Diplomat Mine (fig. 3) water has been introduced to the base of the spoil, particularly at early times after mining. The pond level, at approximately 722 m above sea level, produces a comparable hydraulic head at the base of the spoil adjacent to the pond. This hydraulic head has been distributed laterally outward, particularly toward site BR37, and to a lesser degree toward BR51, both of which have shown increases in hydraulic head of about 1 m since 1980-81 (fig. 3).

A comparable situation exists near pond S-20 at Vesta Mine. Even as recently as 1986 the head in pond S-20 was 5 m higher than the hydraulic head at the base of the spoil at two sites immediately adjacent to the pond, despite the fact that water levels have increased continuously at these sites during the 5-year period of observation. The effect of this leakage from pond S-20 can be seen as far as 800 m south at site BR52, in the form of steadily increasing heads at the base of the spoil (fig. 4).

Downward Seepage from Shallow Ponds

Shallow ponds located in spoil at all four mines for which data are available, give evidence of losing water into the spoil during part or all of the year. Most of the ponds appear to be connected to the water table, but some are perched with unsaturated spoil lying between them and a deeper water table.

Figure 3.—Aerial photograph of PHRP instrumented study in reclaimed terrain in the western part of Diplomat Mine

The net loss of water from ponds to the groundwater flow system has been calculated for three shallow, permanent ponds at Diplomat Mine and two shallow, permanent ponds at Vesta Mine (table 1). The three shallow ponds at Diplomat Mine were contributing water to the spoil groundwater flow system in 1985 and 1986, at a rate that corresponds to approximately 0.1 to 0.2 m per year when expressed as a height of water applied over the instrumented area. At early times after mining, when vertical hydraulic gradients were much higher, it is likely that these ponds were contributing significantly more leakage to the groundwater system.

At Vesta Mine the combination of relatively high hydraulic conductivity and large gradient below ponds S-21 and S-22 is reflected in a very high seepage rate (table 1), such that the total contribution of shallow pond leakage to the groundwater corresponds to 2.0 cm of water per year over the area of the instrumented site. Leakage of this magnitude is certainly significant in terms of resaturating the spoil at Vesta Mine.

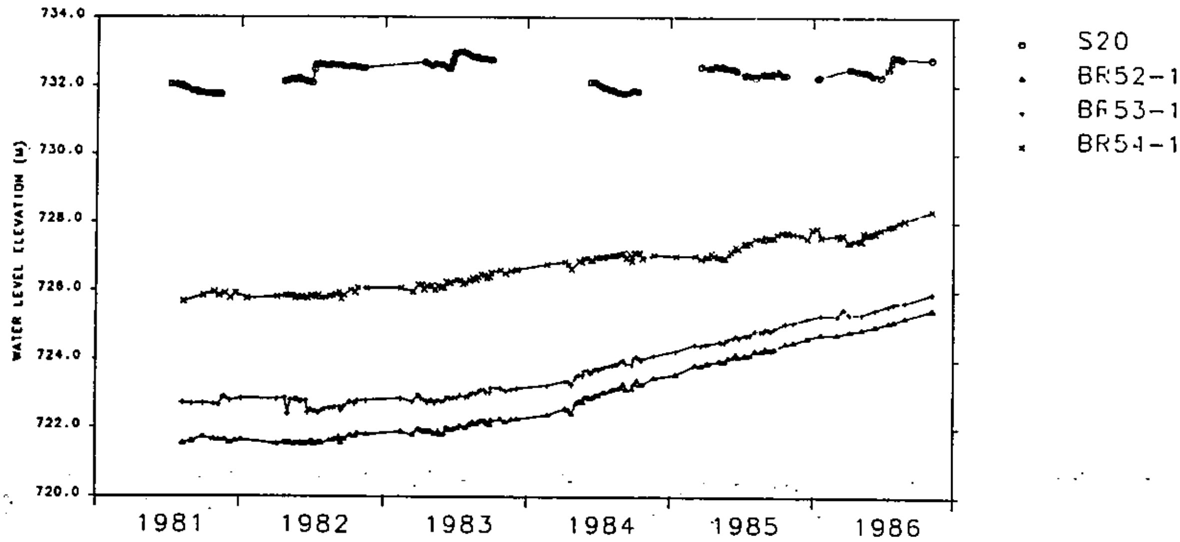

Figure 4.--Hydrographs of wells at the base of spoil in Vesta Mine, showing water-level recovery, in response to leakage from deep pond S-20

In addition to shallow permanent ponds, ephemeral ponds are responsible for significant spoil resaturation. At Diplomat and Vesta Mines, for example, such ponds form in abundance in the shallow closed depressions that dot the reclaimed landscape. These depressions, which appear to be settlement-related features, hold water primarily in the spring and during major rainfall events. During the spring, when evapotranspiration is low, most of the water in the ponds infiltrates into the spoil. Although some of this water is subsequently returned to the atmosphere by evapotranspiration during the summer, some remains to produce groundwater recharge.

A study of 16 ephemeral depressions at Diplomat, Vesta, and Paintearth Mines (table 2) showed that 70% of the water in the depressions in early March 1986 had infiltrated by early May, with the remaining 30% lost to evaporation. On the basis of available data on antecedent moisture conditions, it was calculated that 50 to 70% of he infiltration became recharge. At these sites, such ephemeral ponds cover from 4.5 to 5% of the land surface. We thus calculate that this single spring recharge event corresponded to about 0.2 to 0.3 cm of groundwater recharge when expressed as a height of water applied uniformly over the instrumented area.

The significance of these ephemeral depressions in contributing to spoil resaturation is underscored by data on stable isotopic composition of water from permanent ponds, ephemeral ponds, and spoil groundwater. In late March, water in these depressions has a stable isotopic characteristic typical of spring precipitation with $\delta\ ^{18}O$ values of -18 to -23 per mille. As spring progresses, the water in the depressions becomes isotopically heavier, developing a slight evaporitic character by May. The isotopic composition of this water is strikingly similar to that of the groundwater in both Diplomat and Vesta Mines, which strongly suggests that seepage from these ephemeral ponds is a major contributor to resaturation and continued recharge of the spoil groundwater.

Table 1.--Annual leakage from permanent ponds in reclaimed terrain, Battle River mining area

Mine	Total annual leakage, m^3		
	Pond ID	1985	1986
Diplomat	S- 9	506	475
	S-17	274	105
	S-19	203	100
	Total	983	680
Vesta	S-21	10 093	9 152
	S-22	8 560	9 458
	Total	18 653	18 610

PROJECTION OF STEADY-STATE WATER-TABLE POSITION IN MINE SPOIL

Method of Analysis

Water-level trends at Diplomat and Vesta Mines were evaluated at about 20 sites where

Table 2.--Infiltration and recharge from ephemeral ponds

Mine	Number of ponds	Pond area (m^2)	Infiltration (m^3)	Recharge (m^3)
Diplomat	8	8660	842	420
Vesta	7	9110	619	310
Paintearth	1	275	18	9

five to seven years of records are available. These water level records were analysed by empirically fitting curves to the data and extrapolating the ultimate steady-state water-table position from the curves.

The raw hydrograph data from the wells used for predicting steady-state water-table position had several shortcomings. Seasonal and weather-induced variation was generally extreme, and measurements tended to be concentrated in the summer and fall. To circumvent these problems, a 2-stage data smoothing process was employed. First, a monthly average water level was calculated. For months in which no measurements were available, a value for missing months was interpolated using the two readings from before and after the hiatus. The smoothed record for each year, consisted of 12-monthly average values. An annual average was calculated from the 12-monthly values to eliminate seasonal variation.

Each well used for curve-fitting, therefore, had one point for every year for which data were available. The year in which each site was mined was determined from maps of mining progress at the two mines. It was assumed that immediately following mining and backfilling, the water-table position corresponded to the elevation of the pit floor.

All of the wells at Diplomat Mine and most of the wells at Vesta Mine displayed water-level recovery patterns that were inverse-exponential in nature (fig. 5). That is, the initial rate of recovery was rapid, followed by a steadily decreasing rate of recovery, that eventually leveled off asymptotically at a level corresponding to the final equilibrium water-table elevation. This type of water-level recovery is analogous to that upon which single well response test analyses are based. Clearly the massive disruption of the overburden aquifer material and associated hydrogeologic environment by mining will give rise to some degree of nonideal response in the recovery of water levels in spoil as compared with a typical aquifer test. The general form of the equation that describes this recovery and to which data from most of the wells at Diplomat and Vesta Mines were fitted using the "Fit-Function" feature of the RS/1 software (BNN Research) is given as equation (1).

$$H_t = -Ce^{(-t/B)} + D \qquad (1)$$

where

- H_t is hydraulic head at time t
- C is a constant that includes all the physical parameters of the aquifer and well geometry
- B is a constant that accounts for lagged response caused by the nonideal behaviour of the spoil aquifer
- D is a constant that represents the static post-mining hydraulic head.

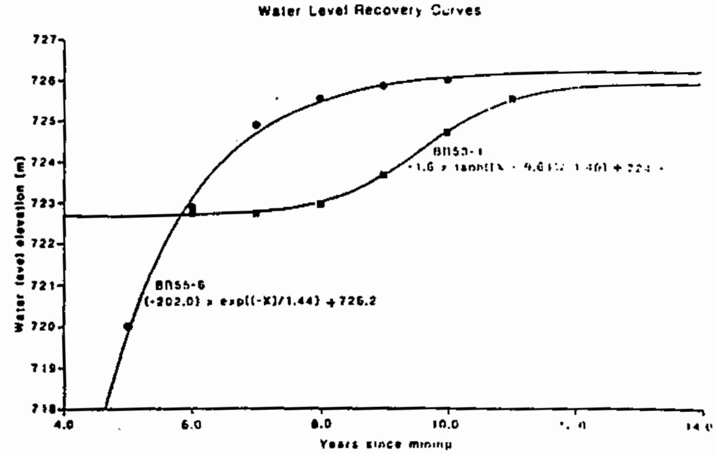

Figure 5.--Calculated water level recovery curves for spoil wells at Vesta Mine, showing the inverse exponential (BR55-6) and the hyperbolic tangent (BR53-1)

A group of wells at Vesta Mine displayed a water-level recovery pattern that was distinctly different from the majority of the wells (fig. 5). The recovery curves from these wells had a flattened, subdued S-shape, characterized by a period of very slow recovery at early times, a period of relatively rapid recovery at intermediate times, tailing off to a period of gradual stabilization at later times. Response of this type is sufficiently nonideal to be unsuitable for curve fitting to the semi-empirical equation (1). In fact, recovery of this type appears to be beyond the approaches characterized in the hydrogeological literature. Consequently, a fully empirical approach was adopted for these wells, fitting the recovery curves to a function of an appropriate mathematical form, but with no physical or theoretical basis.

The functions that provide the required curve form are most commonly the complimentary error function types or hyperbolic types. Only the hyperbolic types were available in the RS/1 software; therefore, the recovery curves were fitted by a least-squares method using a TANH (hyperbolic tangent) function of the form

$$H_t = C \text{ TANH } ((t - B)/E) + D \qquad (2)$$

where the parameters B, C, and E combined to determine the height, length, and slope of the curve, and parameter D defines the inflection point of the "S" shaped curve. This hyperbolic curve-fitting was best suited to wells where the period of record included the inflection point of the recovery curve, i.e., sites where the water level had recovered by more than 50%. Since the hyperbolic recovery curve is symmetrical about the inflection point, the lower part of the curve (i.e., at early times) plus the inflection point uniquely defines the shape of the curve.

Results

Using this approach, steady-state water-table predictions were made for 12 wells at Diplomat

Mine and 8 at Vesta Mine. For 10 wells in the 63.8 ha detailed study site at Diplomat Mine (fig. 3), mean water-level recovery was calculated to be 95% complete, with individual wells varying from 86 to 100% recovered. At two other areas in Diplomat Mine, recovery values of 90% were calculated. At the detailed study site at Vesta Mine, seven of eight wells indicated a mean recovery of 86%, with individual wells ranging from 62 to 100%. One well indicated only 33% recovery, but the data set is suspect, and it is likely that recovery at this site is more nearly complete.

Water-table levels at Highvale Mine are generally very stable or show a gradual decline. Consequently, we conclude that the water-table position at this instrumented site is similarly at or very close to its equilibrium position, even though no calculations were made.

In newer areas of Vesta and Paintearth Mines, spoil resaturation has just begun. Only a few wells at the base of the spoil show any rise in water levels at all. It is not possible, therefore, to project where the stable water table will be.

Rate of Spoil Resaturation

The rate of spoil resaturation can be illustrated by the length of time required to reach a specified degree of water-level recovery. As can be seen in table 3, water-level recovery is somewhat more rapid at Diplomat Mine than at Vesta Mine, presumably a reflection of the greater thickness and lower permeability of spoil at Vesta Mine. It should be noted that no such relatively rapid reestablishment of a post-mining equilibrium groundwater regime is occurring in the more recenty mined areas of Vesta or Paintearth Mines. Although these areas were mined from four to seven years ago, there is no evidence of significant resaturation. The apparently slower restablishment of a stable water table in spoil in these areas may be related to differences in the spoil, which is generally about 20 m thick and is of generally low permeability. It is more likely, however, that the absence of major surface ponds, and especially deep ponds that recharge the base of the spoil, is responsible for the differences between these settings and the older instrumented sites.

EXAMPLE OF EQUILIBRIUM GROUNDWATER REGIME IN RECLAIMED TERRAIN

Water-Table Characteristics at Diplomat Mine

The position and response of the water table in Diplomat Mine provide an insight into the conditions that are likely to characterize stable post-mining landscapes that contain lakes and ponds.

The water table is dominated by a large water-table mound at approximately 724 m

Table 3.--Rate of spoil resaturation

	50% Recovery		95% Recovery	
Mine	Mean	(Range)	Mean	(Range)
Diplomat	4	(0.9 to 8.0)	12.9	(3.0 to 19.6)
Vesta	5.8	(1.3 to 12.6)	15.1	(5.7 to 28.2)

elevation, situated near the centre of section 1 (fig. 3). This mound is associated with several ponds and depressions located in troughs between remnant spoil piles, in a position that is relatively high in the landscape, at 725.1 to 725.7 m. Groundwater flow is radially outward from this mound with heads dropping off to about 721.5 to 722 m in all directions. The water-table mound results from direct recharge through this series of generally deep ponds that include sites BR71, 170, and 171, among others (fig. 3).

These upland ponds and depressions represent areas in which the water table is within 1.5 m of the surface; the net direction of groundwater movement is downward and away from the ponds. The hills in the reclaimed landscape at Diplomat Mine, as represented by those at site BR107 and BR104 (fig. 3) represent areas of deep water-table conditions where little or no groundwater recharge is occurring. It appears that nearly all of the precipitation and snowmelt that occur in these settings infiltrates only to shallow depths or runs off. The small increases in water-table elevation that are recorded at these settings represent lateral movement of recharge pulses from the nearby upland depressions. The same is probably true to a great degree for midslope sites such as BR103, 105, and 106 (fig. 3).

It is not known whether the water-table situation around the upland depressions and ponds at Diplomat Mine represents a near equilibrium condition or whether the water table will continue to rise in the areas between the ponds. Examination of similar landscape settings in undulating to rolling unmined terrain suggests that the present configuration may be nearly at equilibrium. Two recently published studies from Saskatchewan and Manitoba report similar relationships between ponding and water-table position in undulating to rolling terrain containing ponds. Data from near St. Denis, Saskatchewan (Miller et al. 1985, p. 297-301) and Hameota, Manitoba (Mills and Zwarich 1986) document the presence of water-table mounds beneath depressions and ponds that rise well above the level of relatively stable intervening low areas on the water table that underlie hills and non-ponded flats.

Ponds in lowland settings, such as S-9, S-17, and S-19 (fig. 3) represent a somewhat different situation from their upland counterparts. These ponds typically receive discharge from the groundwater system during part of the year, and lose water to the groundwater system at other times, although available data show that they are net contributors to the groundwater system. Because of their position in the landscape, the water table around these ponds is at a relatively shallow depth for some distance beyond their edges. The level of these ponds appears to be controlled by an equilibrium between the rate of water loss from the ponds and the rate at which groundwater is drained from the system at the base of the spoil.

Surface Water-Groundwater Interactions at Diplomat Mine

The response of the water table over time at Diplomat Mine varies with topographic setting. Three characteristic settings have been identified: (1) Flat lying areas and lower slopes where the depth to water table is less than 2.5 to 3 m below ground surface; (2) Upland hills and midslopes where the depth to water table is greater than 2.5 to 3 m; and (3) Areas adjacent to permanent ponds where the water table is less than 1.5 m deep.

In flat-lying areas where the water table is less than 3 m deep such as sites BR65 and BR68 (fig. 3), the water table responds strongly to spring snowmelt and major precipitation events. In well BR68-3 (fig. 6), for example, spring snowmelt produced a water-table rise of 2.6 and 1.65 m in 1985 and 1986, respectively. From the snowmelt peak, the water table in this setting recedes over the summer months. Major precipitation periods, such as the 108 mm of rainfall in August 1985 or the 180 mm of rainfall in July 1986, produced water-table increases of 0.73 and 1.71 m, respectively; in the latter case, exceeding the rise caused by spring melt. Subsequent to these recharge events, water-table recession occurs, with annual lows occurring during the late winter (February to March).

In upland and midslope settings, such as sites BR40, 66, and 109 (fig. 3), where the water table is deeper than 2.5 m, two characteristics of water-table response are dominant: (1) The magnitude of water-table rises and declines is reduced, and (2) The arrival of recharge events at the water table is delayed. At well BR66-4 (fig. 7), for example, the water table is from 3.8 to 4.2 m deep; the water-table peak corresponding to spring melt is delayed well into the summer, occurring usually in August. The magnitude of the water-table rise from this recharge is relatively small, for example, 0.28 and 0.20 m in the spring of 1985 and 1986, respectively. The major precipitation events of August 1985 and July 1986 show a similar delay in arriving at the water table. The August 1985 precipitation produced a rise in water table in well BR66-4 of 0.16 m, peaking in mid-October 1985. Similarly, the July 1986 precipitation produced a rise of 0.21 m with the peak occurring in early November 1986.

In the third setting, next to permanent ponds where the water table is less than 1.5 m deep, the water-table elevation is very close to the level of the pond, and water-table response tends to parallel, both in time and in magnitude, changes in pond elevation. The exception to this pattern occurs during the winter months when the water table declines, presumably because of the formation of overlying ground frost, whereas the pond freezes at a level corresponding to its late fall value. Well C39-C at site BR39 shows a water-table response typical of this type of setting (fig. 8). The water table in this well ranges from 0.4 to 1.2 m deep. During the winter, the water table at this site is from approximately 1.0 to 1.1 m lower than the level of the frozen pond. Spring snowmelt causes the pond level to rise, although, the magnitude of the increase is not known because the pond gauge is frozen or partly frozen during the early part of the thaw. The spring melt produced water-table rises of 0.81 and 0.85 m in 1985 and 1986, respectively, bringing the water table up close to pond level. In 1985, both the water table and pond levels peaked on May 14; in 1986, the water table maximum lagged behind the pond level peak by three to six weeks. Prior to the August 1985 rainfall, both

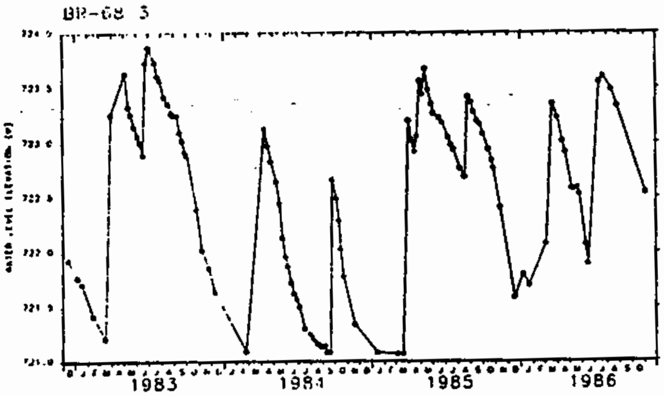

Figure 6.—Hydrograph of well BR68-3 showing water-table response to recharge events

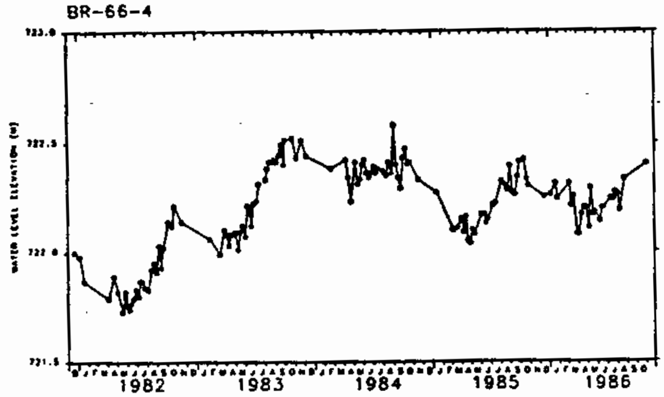

Figure 7.—Hydrograph of well BR66-4 showing water-table response to recharge events

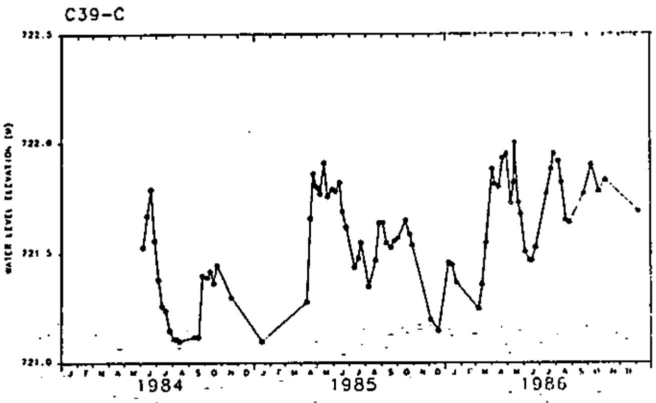

Figure 8.--Hydrograph of well C39-C showing water-table response to recharge events

the well and the pond had reached minimum levels on August 7; following the rain a peak was recorded on August 27. The pond level rose 4 cm in response to this event, and the water table rose by 29 cm, probably reflecting some contribution from capillary water above the water table. The similarities between pond and water-table response in July 1986 are more striking. After both had declined to a low level on June 17, 1986, water levels in both the pond and the well rose to maxima on July 29 in respone to the July rainfall. The increase in pond level of 33 cm in response to this rainfall was very closely paralleled by a 48 cm rise in the water table, the water-table response again greater because of the contribution of capillary water to reducing the unsaturated porosity above the water table.

IMPLICATION OF ELEVATED GROUNDWATER LEVELS IN RECLAIMED LANDSCAPES

The elevation of the stable, steady-state water table in a reclaimed landscape has several important implications for the impact of the mined area in the environment. Where the water table is in close proximity to the land surface, capillary forces can transport salt to the root zone or the surface causing progressive salinization of the soil. Where the water table in the spoil is above the level in adjacent unmined land, water of degraded chemical quality can migrate out of the spoil to contaminate aquifers or produce saline seeps (Trudell and Moran 1984; Trudell et al. in press).

Using the equilibrium water-table elevations from the analysis above, it is possible to estimate the total acreage of the detailed study site at Diplomat Mine that is subject to degradation by soil salinization (table 4). As shown by Moran et al. (1986), accumulation of salt

Table 4.--Steady-state water-table position, area at risk to salinization Diplomat Mine detailed study area (total area 63.8 ha)

Depth to water table	1986		Equilibrium (predicted)	
	ha	%	ha	%
<1.0 m	9	14	24.5	28
1.0 to 2.0 m	11	18	6.5	10
Total <2.0 m	20	32	24.5	38

in the soil zone occurs at Diplomat Mine where the depth to the water table is less than or equal to approximately 1 m. Since both soil salinization and water level stabilization are relatively long-term phenomena, it is assumed that all of the area in Diplomat Mine where the water table is less than 1 m deep will eventually salinize and, consequently, will be lost to agricultural production. Based on 1986 water-table conditions, the acreage susceptible to salinization (water table less than 1 m deep) is 9 ha or 14% of the total area (table 4). Based on the projected final water-table position, this acreage will eventually double to 18 ha, or 28% of the total detailed study area at Diplomat Mine. In addition, in natural slope settings close to Diplomat Mine, which represent long-term equilibrium condition, severe soil salinization is found in places where the water table is as much as 1.5 m deep. In this potential or border-line zone where the water table is between 1 and 2 m deep, the area at risk at Diplomat Mine is expected to decrease from 11 ha (18%, 1986) to 6.5 ha (10%) under equilibrium water-table conditions.

The total acreage at risk, that is with less than 2 m depth to water table, is expected to increase from 20 ha (32% of the total) in 1986 to 24.5 ha (38% of the total) under equilibrium conditions.

ACKNOWLEDGEMENTS

This study has been partially funded by Alberta Heritage Savings Trust Fund through the Land Conservation and Reclamation Council of the Alberta Government. This project would not have been possible without the assistance and support of Luscar Ltd., Manalta Coal Ltd., TransAlta Utilities Ltd., and Alberta Power Ltd.

We would like to thank Maria Tatchyn for her assistance in preparing the text. Special thanks are extended to Daphne Cheel, who provided assistance by editing the manuscript, preparing the figures, and laying out and assembling the final manuscript.

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