# GROUNDWATER CONDITIONS AROUND A COAL-COMBUSTION RESIDUE SITE IN SOUTHERN ILLINOIS

by

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Abstract.  Coal-combustion residues, predominantly composed of scrubber sludge, served as backfill to an abandoned surface-mine pit.  A low-relief valley now trends across the area that was once the old pit, replacing the former hummocky terrain left by the mining operations. Twelve wells, installed within and adjacent to the fill, provide data on hydraulic head at the base of the spoil, in the coal, and in the coal-combustion residues.  The bases of the screens ranged in depth from 5.6 to 15.9 m.  Three of the wells were sampled for groundwater chemistry. Hydraulic conductivity of the spoil from nine falling-head (slug) tests ranged from $1.9 \times 10^{-7}$ to $4.1 \times 10^{-3}$ cm/s, with a geometric mean of $1.8 \times 10^{-4}$, somewhat greater than the $9.8 \times 10^{-6}$ cm/s hydraulic conductivity of the coal-combustion residues.  The mine spoil is heterogeneous, composed of disturbed surficial sediment, including loess and diamicton, blended with fragments of bedrock.  Prior to reclamation, groundwater flowed away from the pit lake to topographic lows to the north, east, and south.  Reclamation has not altered groundwater flow significantly.  A two-dimensional numeric random-walk contaminant-transport model, based on 1) properties of the coal-combustion residue as determined from column studies, 2) data from a finite difference model of groundwater flow at the site, and 3) conservative estimates of dispersivity and porosity, suggests that leachate generated by the fill poses little threat to ambient groundwater quality.

Additional Key Words:  Groundwater Modeling, Groundwater Quality, Mine Land Reclamation

## Introduction

In an effort to meet new federal emission standards, power companies rely on scrubbers or employ new coal burning technologies, both of which lead to increased production of coal-combustion residues.  Although these materials have numerous applications, including structural fill, light-weight aggregate, stabilization material, drilling fluid, and additive to Portland cement, production will exceed demand for the foreseeable future. Today, most excess residue produced from coal-combustion is either buried near the surface in a relatively dry state (landfill) or pumped into slurry ponds (Bahor and others, 1981), both of which take land suited for other purposes out of production, at least temporarily.  Reclaiming abandoned strip-mines with these residues reduces the loss of productive land and returns otherwise non-productive and hazardous land to more productive use.

Coal-combustion residues, however, may produce a leachate containing hazardous substances. Numerous previous studies have investigated the environmental impact of coal-combustion residue disposal

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sites on surface water and groundwater quality (Villaume and others, 1983; Le Seur Spencer and Drake, 1987; Cherkauer, 1980; Hardy, 1981; Simsiman and others, 1987; Sakata, 1987; Theis and others, 1978; Beaver and others, 1987; Fruchter and others, 1988; Gerber, 1981; Le Seur, 1985; Hall, 1977; Rai and others, 1989; Rehage and Holcombe, 1990; Libicki, 1978; U.S. Waterways Experiment Station, 1979). Some of this research detected distinct contaminant plumes in the groundwater, downgradient from slurry ponds and landfills. In some cases, contaminants exceeded drinking water standards. Adriano and others (1980), Ferraiolo and others (1990), Theis and Marley (1979), and Theis and Gardner (1990) provided general reviews on residue disposal methods and environmental impacts.

This paper presents intermediate results of a long-term study of the environmental impact of filling an abandoned strip-mine pit in southern Illinois with coal-combustion residues. An unstable highwall associated with the pit threatened a county road. The immediate area lacked sufficient spoil needed to fill the strip-pit and establish a gentle graded contour. Coal-combustion residues, predominantly composed of flue-gas desulferization scrubber sludge with lesser amounts of fly ash, herein referred to as *residues*, served as a backfill.

## Site Description

### General Setting

The study area is an abandoned strip-mine located within the Herrin 7.5-Minute Topographic Quadrangle, just east of Energy, in Williamson County, Illinois. A private landfill and the Herrin Municipal landfill are located in the section to the north. The test site (figure 1) was an abandoned strip-pit lake that was partially filled with debris from the surrounding spoil piles and an adjacent highwall. The pit, which was about 315 m long, 50 m wide, and up to 12 m deep (as measured from the top of the highwall), was filled in stages. Initial work during the summer of 1993

reclaimed the western 90 m of the pit, with the residues filling the first 70 m of the pit behind a 20-m-wide spoil dam. Reclamation was completed during the summer of 1994, with residues filling the next 90 m and spoil filling the remaining 135 m of the pit. Two other abandoned pits are nearby, one to the west of the disposal site (West Pit) and the other to the south and east (South Pit).

Pre-strip-mining topographic maps clearly show that the test site was located on a drainage divide. Flow from the adjacent drainage basins emptied into the Big Muddy River to the north. At present, no distinct surface drainage flows away from the project site, as surface mining operations have disrupted the original drainage pattern and created a hummocky terrain, characterized by numerous small hills, swales, and depressions. Reclamation associated with the placement of the coal-combustion residues has created a more subdued topography with a gentle slope trending to the east in place of the abandoned pit.

### Geologic Setting

The test site is on the southern edge of the Illinois Basin and lies within the outcrop zone of the Carbondale Formation (Pennsylvanian). The Paleozoic strata dip gently to the north toward the center of basin. No major faults exist within a 1.6 km radius of the project site. About 5 km to the west, however, several distinct fault systems cut the Pennsylvanian rocks. The Carbondale Formation is characterized by numerous shale, sandstone, limestone and coal members, many of which are not laterally continuous. Complex depositional environments resulted in abrupt lateral facies changes (Willman and others; 1975).

The undisturbed surficial deposits of the study area originated directly and indirectly from glacial processes. Less than 4 m of Illinoian Age glacial diamicton (Glasford Formation) and 2 m of Wisconsinan Age loess (Peoria and Roxana Silts)
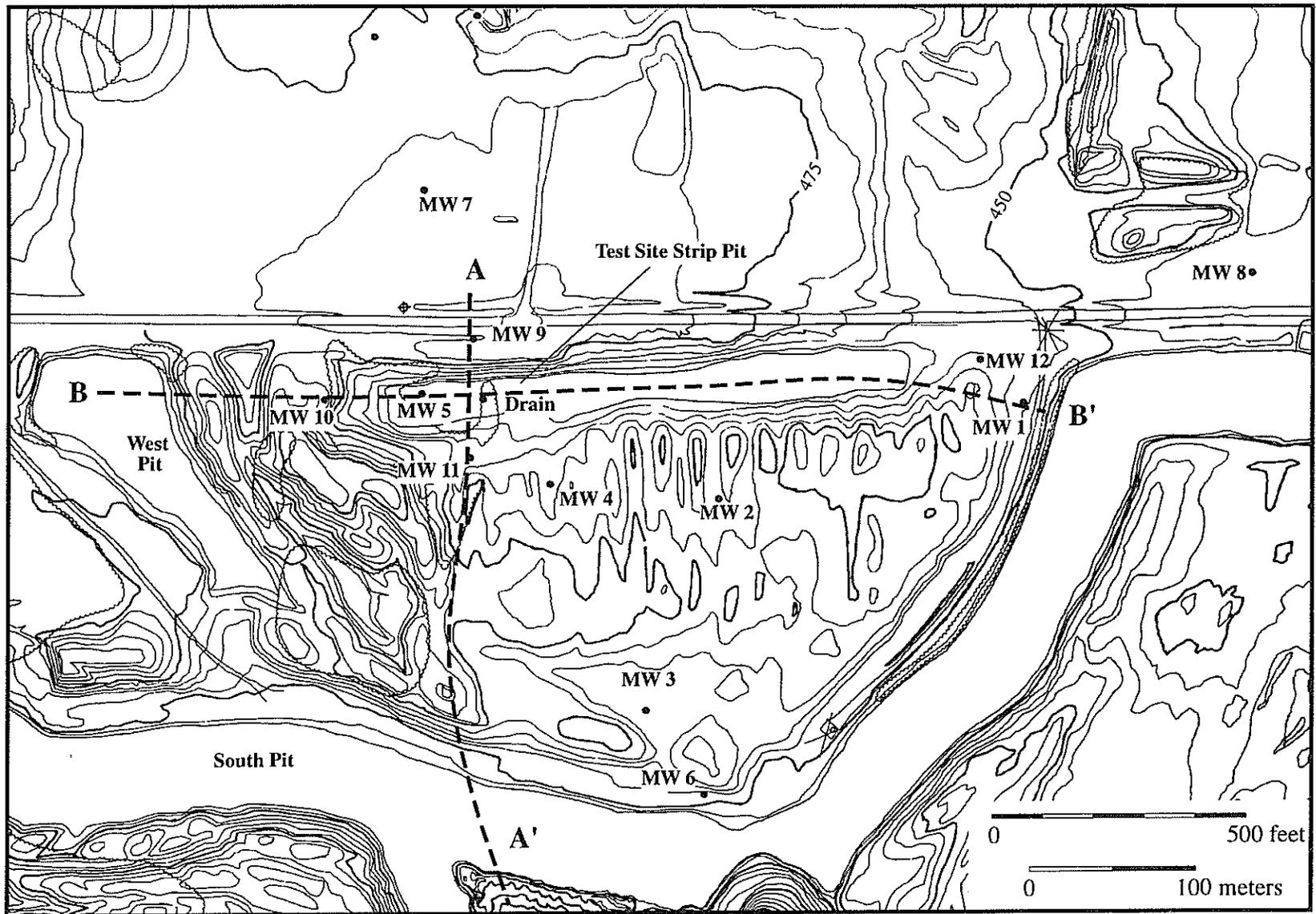
Figure 1. Topographic setting and location of the groundwater monitoring wells and geologic sections. Contour interval is 5 feet.

unconformably overlie the Pennsylvanian strata (Willman and others, 1975).

Strip mining in the study area removed up to six feet of the Herrin Coal seam and all overlying strata, with subsequent replacement of the overburden as spoil. The top of the Herrin Coal is generally at an elevation of about 137 m in the area of the test site. Mine spoil, a mixture of the natural surficial materials and bedrock fragments, constitutes the bulk of the materials on the land surface at the present time. In some places, the spoil consists almost entirely of rock fragments. In other areas, fine-textured matrix materials support the rock fragments.

Two geologic cross-sections (AA', figure 2, and BB', figure 3) constructed from data collected during the installation of monitoring wells, illustrate the general stratigraphy of the study area. Mine spoil lies unconformably on top of strata which underlie the Herrin Coal. Strip-mining operations apparently never removed the coal from beneath the road, but excavation of the highwall proceeded up to its edge.

The Herrin Coal remains in only a few places near the test site. Mining in these areas was either not economic or would have destroyed roads or town structures. Abandoned underground mines also exist near the project site. About 400 m to the north of the test site, the Herrin and Springfield Coals were removed from a room-and-pillar mine, which has since partially collapsed, leaving small subsidence troughs on the surface (Patrick Engineering, 1990).

## Hydrologic Setting

Pryor (1956) studied the availability of groundwater in the southern Illinois area, including Williamson county. The report makes no reference to the quality of the water from subsurface supplies and suggests that bedrock units near the test site do not generally yield water, although Pennsylvanian strata elsewhere in the county are capable of sustaining small domestic supplies from depths of 15 to 250 m.

Environmental studies associated with the landfill north of the test site indicate that a shallow unconfined flow system has developed in the spoil and upper, more permeable bedrock units. Reports associated with these projects suggest approximately 3 to 8 m of mine spoil just above the shale unit which presumably underlies the Herrin Coal. Saturated conditions were encountered in all the wells in the unconsolidated materials, suggesting that the shales retard the flow of water moving through the mine spoil. Hydraulic conductivity measured in the field ranged from $10^{-4}$ to $10^{-6}$ cm/s, with the higher values in wells screened in coal and black shale (Patrick Engineering, 1990). The hydraulic head data from the monitoring wells suggest groundwater flows to the north at the southern boundary of the landfill and to the south at its northern boundary. The northern and southern flows converge and flow to the east near the center of the landfill (Patrick Engineering, 1990).

## Field Investigations

### Well Survey

We were unable to locate anyone utilizing a groundwater supply within a 1.6 km radius of the test site. Well logs on file with the Illinois State Geological Survey (ISGS) and Illinois State Water Survey (ISWS) indicate that some water wells were constructed at the turn of the century, but the more recent logs on file were for coal-, gas- or oil- exploration boreholes. A few of the logs of the exploration boreholes suggest brackish (non-potable) groundwater at depths greater than 150 m. Just outside the 1.6 km radius, several water wells were drilled and subsequently abandoned because of poor production.

### Monitoring Well Installation

A total of twelve groundwater monitoring wells were installed in the study area for this project (Table 1). Three of the wells were designed to
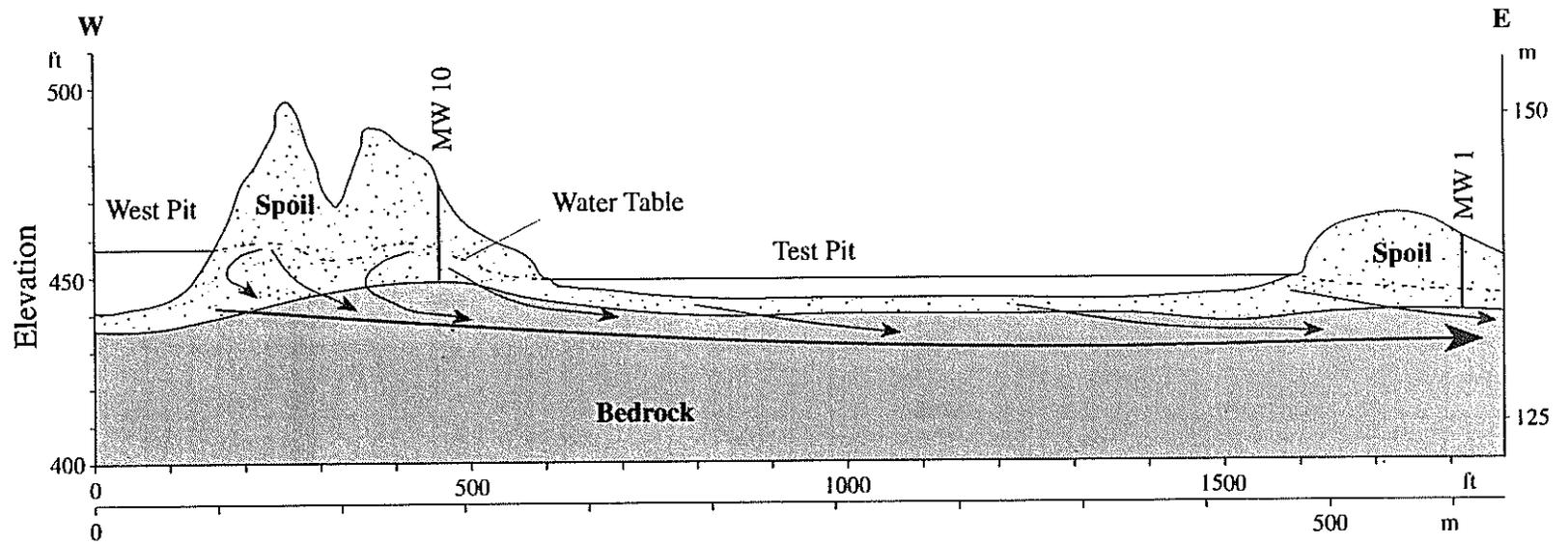
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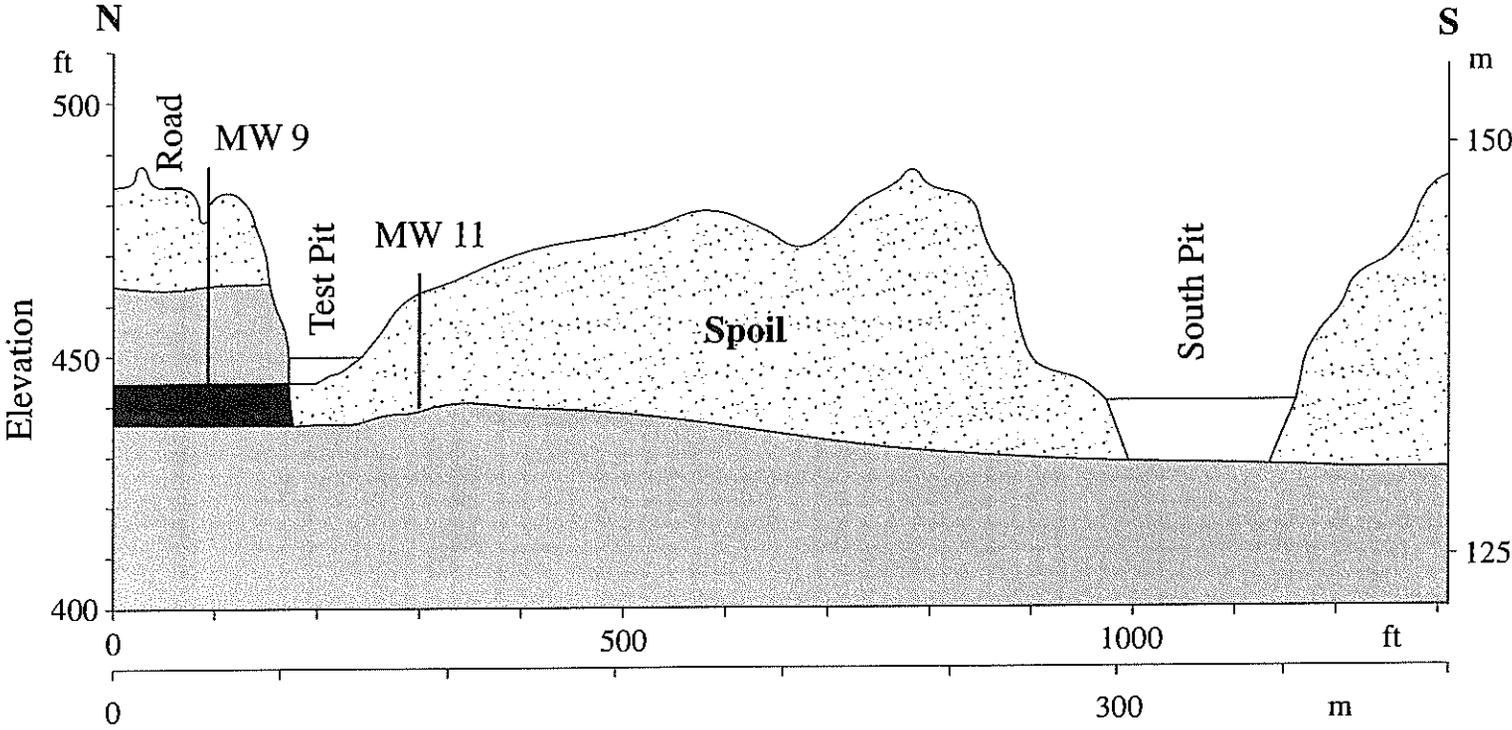
# Cross-Section A-A'



Figure 2. Cross-section showing general stratigraphic relationships along a north-south line through the site. The unit shaded in black is the Herrin Coal. See figure 1 for the location of the section. Verical exaggeration is about 4.95.

## Cross-Section B - B'



Figure 3. Cross-section showing general stratigraphic relationships and a hypothetical vertical flow system for the study area along a west-east line. See figure 1 for the location of the cross-section. Vertical exageration is about 5.46.

Table 1. Hydraulic conductivity measurements on monitoring wells near the test site.

| Monitoring Well | Screened Interval | Maximum Depth (m) | Drilling Method | Hydraulic Conductivity (cm/s) |
|---|---|---|---|---|
| MW 1 | Spoil | 5.61 | 5.25-in Hollow-Stem Auger | $8.4 \times 10^{-5}$ |
| MW 2 | Spoil | 7.15 | 5.25-in Hollow-Stem Auger | $4.1 \times 10^{-3}$ |
| MW 3 | Spoil | 5.63 | 5.25-in Hollow-Stem Auger | $3.3 \times 10^{-5}$ |
| MW 4 | Spoil | 5.78 | 5.25-in Hollow-Stem Auger | $1.8 \times 10^{-3}$ |
| MW 5 | Residues | 10.32 | 5.25-in Hollow-Stem Auger | $9.8 \times 10^{-6}$ |
| MW 6 | Spoil | 5.91 | 5.25-in Hollow-Stem Auger | $1.9 \times 10^{-7}$ |
| MW 7 | Fill/ Shale | 10.36 | 5.25-in Hollow-Stem Auger | |
| MW 8 | Spoil | 3.94 | 5.25-in Hollow-Stem Auger | $8.4 \times 10^{-5}$ |
| MW 9 | Coal | 12.27 | Mud Rotary | $6.8 \times 10^{-5}$ |
| MW 10 | Spoil | 15.89 | Mud Rotary | $5.0 \times 10^{-4}$ |
| MW 11 | Spoil | 6.25 | Backhoe | $1.9 \times 10^{-3}$ |
| MW 12 | Spoil | 9.24 | 6-in Hollow-Stem Auger | $5.7 \times 10^{-4}$ |

sample water quality. These wells, herein referred to as MW 9, MW 10, and MW 11, surround the west end of the fill (figure 1). The installation of MW 9 and MW 10 followed accepted guidelines (USEPA, 1986). Monitoring well MW 11 was installed in a spoil pit excavated with a backhoe. A screen and casing (10.2 cm inside diameter(ID)) was centered in a 25.4 cm ID protective polyvinyl chloride (PVC) pipe prior to backfilling the trench. A successful sand pack around the screen was created by alternately adding a few feet of sand to the annular space between the 25.4 and 10.2 cm pipes, then allowing spoil to collapse around the sand by hydraulically lifting the protective pipe. Filling the remaining annular space continued through the same process, first with bentonite pellets and then with a bentonite cement slurry.

The remaining nine monitoring wells (figure 1) only provide data on

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hydraulic head, and installation methods did not always follow USEPA guidelines. Table 1 summarizes the drilling method. Monitoring well casings were 5.1 cm ID PVC screen and casing. The annular space between the casing and borehole walls was filled with sand to a level at least 30 cm above the top of the screen. A cap of bentonite pellets with a minimum thickness of 30 cm was constructed above the sand pack, followed by either a bentonite cement slurry or a mixture of bentonite and well cuttings until a depth of about one meter. The remaining annular space was filled with either cement or concrete. A plastic outer casing protects the monitoring wells at the surface.

Wells were developed by alternately surging the well with a plug and bailing. All well elevations as well as staff gauges in the lakes within the test site and to the west and south were surveyed to a common datum. Two wells installed for monitoring hydrologic conditions in and around the private landfill located immediately north of the test site provide additional data on hydraulic head.

A 15-m-long drain was constructed in the west end of the test site prior to the initial reclamation work. The drain is a slotted pipe surrounded by quartz silica sand, with access through a vertical standpipe installed in the spoil dam. The drain captures leachate from the residues, prior to any natural attenuation, and provides samples from what is in effect a field-scale leachate column test.

## Hydraulic Conductivity Measurements

Falling-head tests (slug test) were conducted on most wells to collect data on the hydraulic conductivity of the spoil and bedrock (Table 1). A pressure transducer connected to a datalogger with a cable was placed below the water level. A sealed cylindrical plug constructed of PVC and filled with sand was then dropped into the well, raising water level instantaneously. This method prevents contamination of the well by external sources of water. Data on the hydraulic head in the well was recorded by the datalogger along with the time required for the water level to return to within 80 percent of its pre-test level. Data on head and corresponding time were transferred to a personal computer, processed with a spreadsheet program, and analyzed following the procedures described by Hvorslev (1951) to obtain hydraulic conductivity.

## Groundwater Hydrology

### Flow

This section describes the conceptual model of the groundwater flow system for the project site, as well as the topographic and geologic factors that influence the flow system. The model of flow conditions is based on geologic data collected during the installation of the monitoring wells, previous geologic studies of the area, and hydraulic head data from the lakes and monitoring wells. Other observations supplemented these data, such as the locations of seeps and the depths to saturated conditions noted while drilling boreholes for monitoring well installation.

Figure 4 is a generalized map of hydraulic head at or just below the water table prior to any reclamation work. The map is based on head data collected on November 20, 1992, from the lakes and the seven monitoring wells that existed at that time. The head contours indicate that the lake to the west and within the test site recharge the shallow groundwater system. The lake to the south may also be a recharge point, but such an interpretation would require additional head data farther to the south. Water quality data also suggest that the lakes recharge the shallow groundwater. Lake-water quality is better than that from the sampled monitoring wells, indicating a significant influx of meteoric water. The quality of the water flowing from the lakes degrades as it reacts with the spoil.

If the lakes are recharge points, then MW 2 shows what at first seems to be an anomalous head, 8.5 cm higher
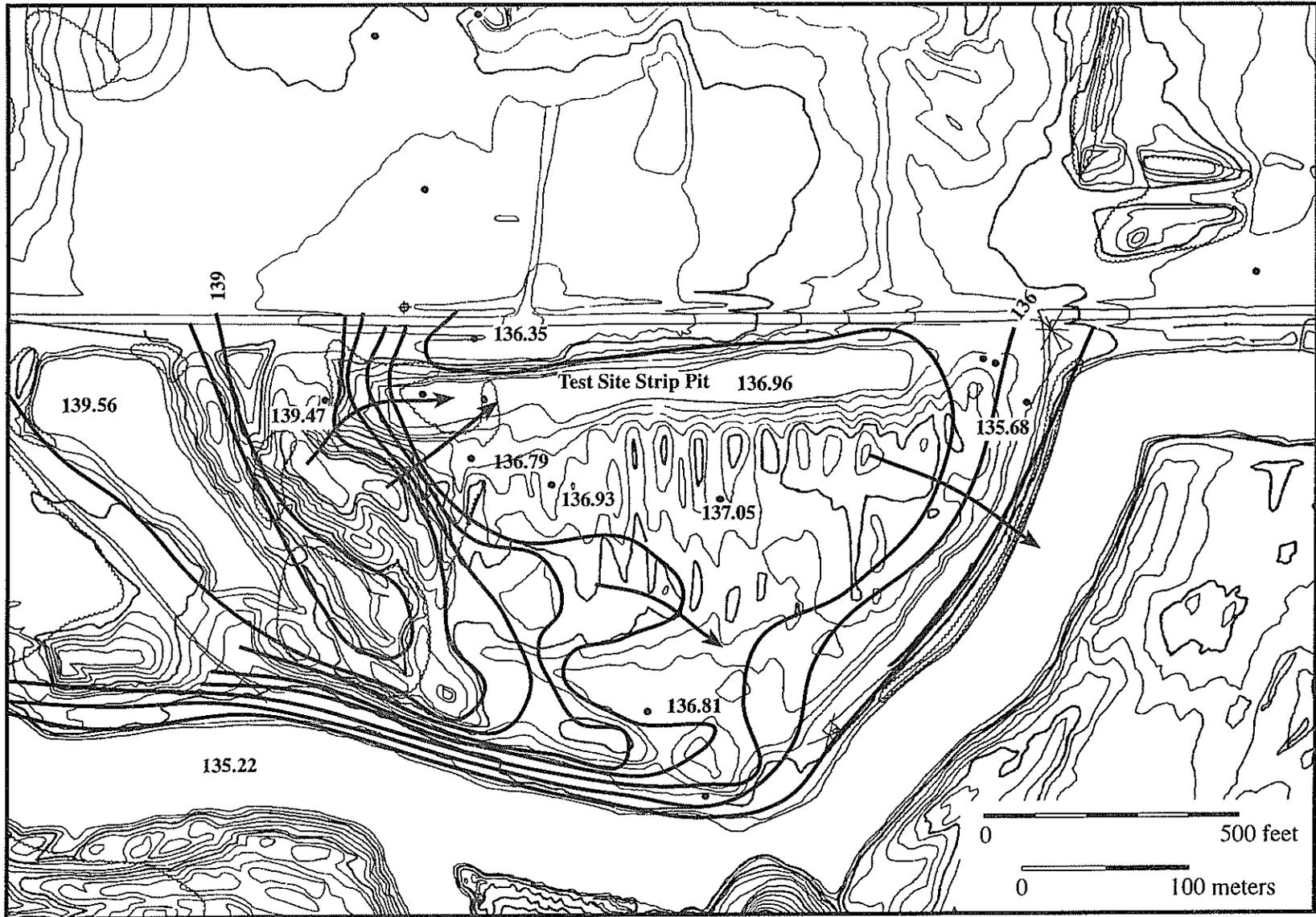
Figure 4. Generalized contour map of hydraulic head at or just below the water table for data collected 11/20/92. Arrows indicate flow direction. Contour interval is 0.6 m.

than the level of the lake water in the test site. Topography, however, influences the general flow pattern at a scale smaller than the map of the groundwater table. If more data were available and the contour interval of head were decreased, smaller local flow systems would become apparent. Typically in a humid temperate climate, like that of southern Illinois, the water table mimics the surface topography. Groundwater recharge occurs over divides, with groundwater discharging into the lows. Observed seeps in the study area suggest this type of system is operating. MW 2 is located near the crest of a spoil pile, and this well is probably influenced by local recharge.

Generally, groundwater flows to the east. Groundwater flows radially away from the lakes and from the center of prominent divides for a short distance before it converges with the general flow system. We need to emphasize that the map is a generalization of a complex flow pattern, ignoring the heterogeneous nature of the spoil. Fractures which can transmit significant quantities of groundwater may be present in the more cohesive spoil. The overall trend, however, does fit the interpretation of flow for the Herrin Landfill located to the northeast (Patrick Engineering, 1990). Flow lines on figure 4 show the shallow flow system at elevations very near the water table. Diagrams like this, however, can cause confusion because they imply horizontal flow when in fact vertical components of flow exist, especially in areas characterized by significant local relief. Figure 3, cross-section BB' (parallel to the interpreted general flow direction from west to east) illustrates the vertical components of flow expected beneath the upland areas.

Why does groundwater flow toward the east? First, mining east of the study area has removed the bedrock units down to the Springfield Coal (Patrick Engineering, 1990). The deep strip-pits and underground mines act as a sink, transmitting significant quantities of groundwater to surface drainage. Second, the study area is

located on a topographic high and the elevated water table associated with this high is driving flow toward the east.

Reclamation has altered the original topography in the study area, but the general trends in groundwater flow have not shifted significantly. A map of hydraulic head from data collected in October 1994, after both stages of reclamation, still suggests flow to the east (figure 5).

The maps of hydraulic head were constructed from data collected from monitoring wells screened at the base of the spoil and in the coal. Investigations on the Herrin Landfill (Patrick Engineering, 1990) installed wells into the shallow bedrock. Hydraulic conductivity measurements conducted on these wells suggest that the shallow bedrock and spoil have hydraulic conductivities of similar magnitude in places. If the spoil overlies bedrock units with a lower hydraulic conductivity (such as gray shale), groundwater may concentrate above the bedrock, with flow along the spoil/bedrock interface. If, on the other hand, the spoil overlies rock with comparable hydraulic conductivity, groundwater would flow in the spoil and shallow bedrock, as indicated on figure 3.

The hydraulic conductivity measured in MW 9 is comparable to other values determined in coal (Table 1). Stone and Snoeberger (1977) measured a maximum hydraulic conductivity of $3.1 \times 10^{-4}$ cm/s for a shallow Wyoming coal. Stoner (1981) reported hydraulic conductivities ranging from $2.3 \times 10^{-4}$ to $8.1 \times 10^{-5}$ cm/s for a shallow coal unit in Montana. The hydraulic conductivity determined in the wells with screens in spoil are comparable to those determined for spoil in other environmental studies in the area (Patrick Engineering, 1990). Table 2 summarizes the representative hydraulic conductivities for the various materials encountered in and around the test site.
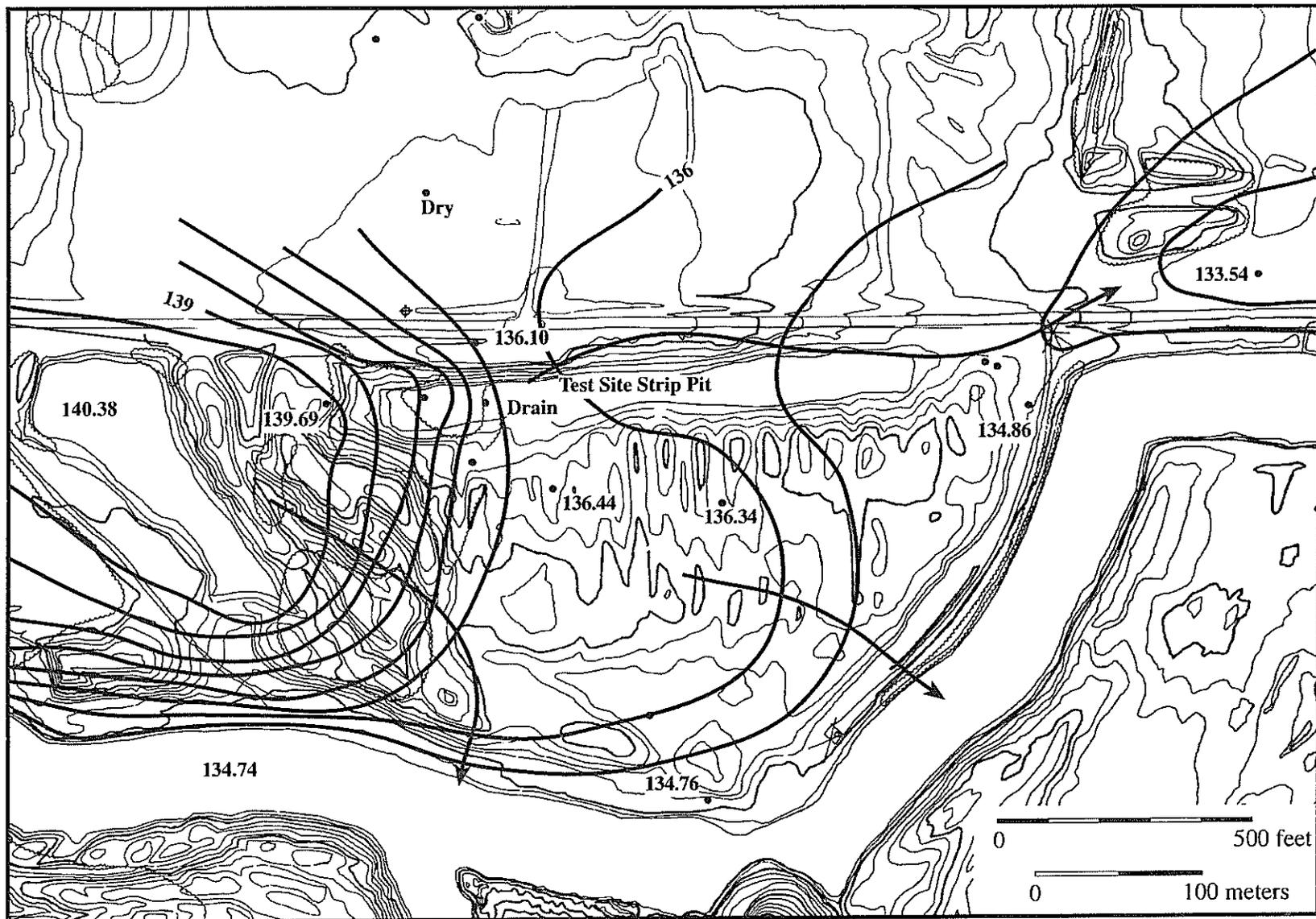
Figure 5. Generalized contour map of hydraulic head at or just below the water table for data collected 10/3/94. Arrows indicate flow direction. Contour interval is 0.6 m.

## Quality

Earlier publications (Paul and others, 1992, 1993; Paul and Esling, 1994) summarized groundwater quality in the vicinity of the test site and the chemistry of the leachate generated from the residues in column studies. Background groundwater at the site shows high levels of iron, manganese, and other metals consistent with water percolating through spoil. Total dissolved solids are about 3,200 ppm, exceeding the level that is considered potable.

Table 2. Geometric mean hydraulic conductivity for materials found near the test site.

| Material | cm/s | n |
|----------|--------------------|---|
| Spoil | $1.8 \times 10^{-4}$ | 9 |
| Coal | $6.8 \times 10^{-5}$ | 1 |
| Residues | $9.8 \times 10^{-6}$ | 1 |

Groundwater collected from MW 10, the upgradient well, was used as a leaching medium in the column studies. Apparently, the residues can remove many of the cations carried in the background groundwater. The chemistry of the waters collected from the drain beneath the residues supports this finding. Column studies do indicate that the residues release boron and molybdenum. Therefore, boron or molybdenum, which are found in low concentrations within the background groundwater, can serve as tracers marking the front of a leachate plume generated by the residues. About one year after the initial reclamation work, but prior to the final fill, groundwater samples from both MW 9 and MW 11 showed an increase in boron concentrations. Boron levels in these wells returned to background levels after the second stage of reclamation.

The column studies suggest that boron and molybdenum are released only with the first flush of the leachate and that concentrations will decrease significantly within a short interval of time. The limited duration of the first flush in the columns raises the question of exactly how long the first

flush will take in the field. Earlier work by Chowdhary (1992) considered columns ranging in size from 4.5 cm to almost half a meter in diameter. His work indicated that leaching through laboratory columns compressed time, with the duration of the first flush proportional to column diameter. A second-degree polynomial curve best described the relationship. Extrapolating the curve beyond the experimental data--a risky undertaking--suggests that a first flush taking one month in a 10.2 cm diameter column would take at least 11 months in the field for a fill of the dimensions placed during the first stage of reclamation. As monitoring continues, the time compression-effect can be better quantified.

## Transport Model

Boron has been detected in samples collected from the drain at the base of the fill at concentrations as high as 104 mg/l. A consistent appearance of boron in one of the downgradient monitoring wells is required for calibrating a contaminant transport model of the site. Nevertheless, a preliminary numeric model can yield some idea of the worst-case contaminant plume that may develop downflow of the disposal area since disposal operations began, and could indicate when contaminants may reach downgradient wells. A numeric random-walk contaminant-transport model was applied to the site for conditions that existed on site immediately following the initial stage of reclamation.

## Model Assumptions

The theory behind the random-walk code developed for this project was described by Prickett and others (1981). The site model assumes uniform, steady, horizontal groundwater velocity in a two dimensional (plan view) flow field. The program requires an estimate of the average linear velocity as calculated from:

$$\bar{v} = \frac{Ki}{n}$$

Where:

| | |
|---|---|
| $\bar{v}$ | Average linear velocity |
| $K$ | Hydraulic conductivity |
| $i$ | Hydraulic gradient |
| $n$ | Porosity |

The heterogeneous nature of the spoil will lead to variable groundwater flow discharges along any flow line. In areas characterized by rocky spoil or fractures, discharge would exceed that of areas dominated by fine-textured spoil. Horizontal gradients suggested by a two-dimensional finite-difference groundwater flow model of site conditions suggest a low average linear velocity. Three simulations were run in order to assess several worst-case scenarios. The simulations are based on three different average linear velocities as determined from the maximum, minimum, and geometric mean hydraulic conductivities for the spoil, a porosity of 0.20, and a hydraulic gradient of 0.02. The hydraulic gradient is the average of the gradients south of the initial fill in the east-west and north-south directions as determined from the flow model. The porosity is on the low side of the range reported for intergranular porosity of fine-textured material and may reflect intergranular transport rather than transport through fractures. The porosity value is conservative, in that it will predict farther transport than some larger value. The simulations also assume a longitudinal and transverse dispersivity of 4.5 and 0.45 m, respectively; these estimates follow a rule-of-thumb that transverse dispersivity is one tenth the value of longitudinal dispersivity (Walton, 1985). Dispersivity values are conservative in the sense that they will maximize concentration downflow, but they are not conservative with respect to the maximum transport distance.

Other assumptions include no reactions between the contaminant and the spoil, no retardation, no additional reclamation work, and immediate saturation of the residues after placement. The source has dimensions 30 m parallel to flow, 50 m transverse to flow in the horizontal plane, and 7 m transverse to flow in the vertical plane. These values approximate the dimensions of the initial fill. The simulations also assume that the source maintains a concentration of boron of 104 mg/l for 11 months then drops to zero. Of course, the assumption of a boron source that reaches a maximum concentration the first day, maintains that concentration for 11 months, and then drops to zero thereafter, is crude. This model of the source is reasonable and conservative, however, considering the limited available data.

## Model Results

The simulations give a worst case scenario with respect to environmental risk. By this we mean that the plumes they predict have higher concentrations at any time period than the plume that would actually develop at the site. The numeric model does allow some real-world features that are difficult to include in analytic models. For example, most analytic models assume either an instantaneous or continuous release of contaminants at the source. With the numeric model, however, the source concentration and duration can be controlled.

Table 3. Chart for converting particle concentration into chemical concentration for the numeric model. This chart assumes that 45 particles correspond to a boron concentration of 104 mg/l.

| Particles | mg/l |
|---|---|
| 40 | 92.4 |
| 30 | 69.3 |
| 20 | 46.2 |
| 10 | 23.1 |
| 5 | 11.5 |

Figure 6 shows the growth of the plume through time as predicted by the simulations. The plume moves slowly
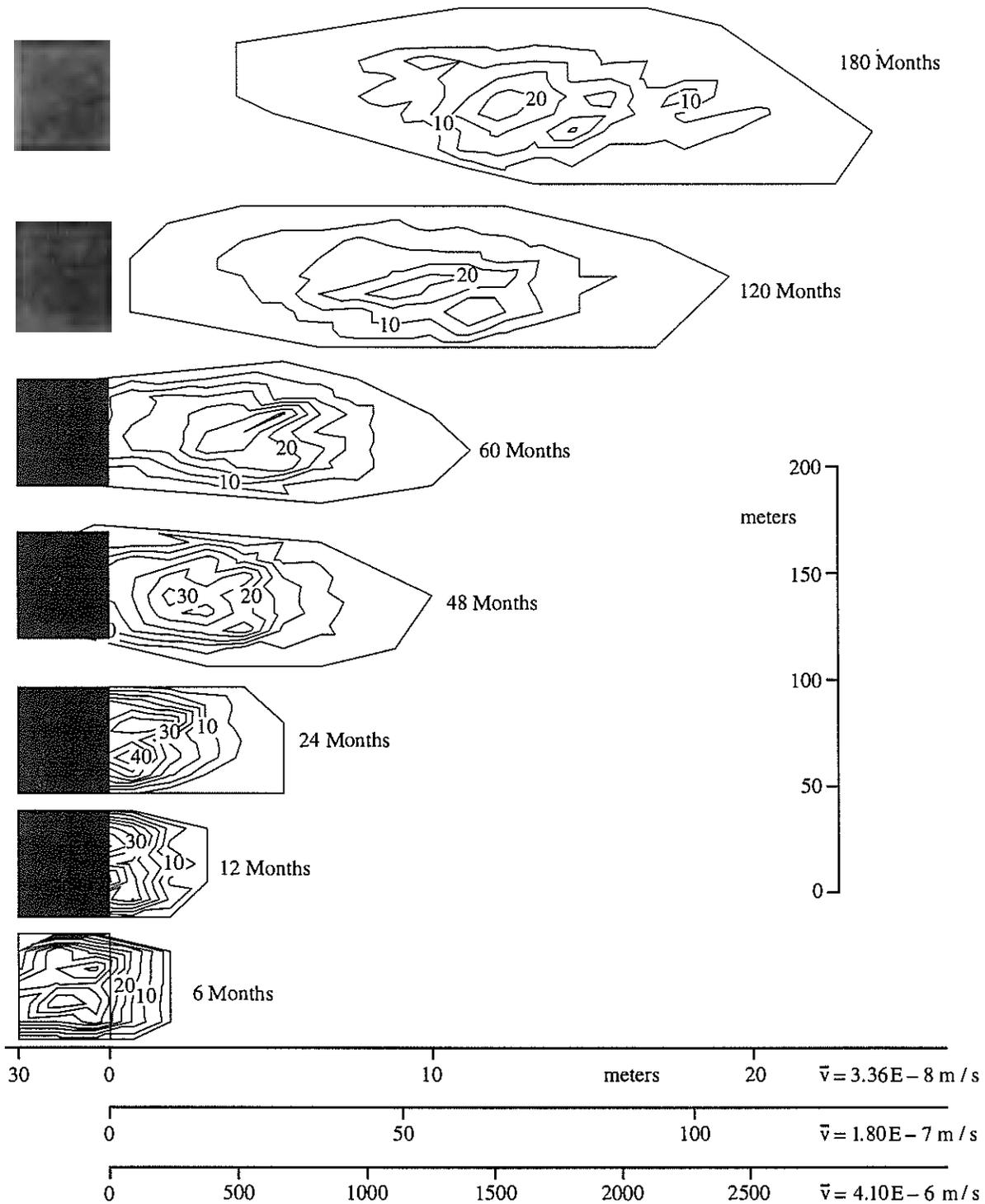
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Figure 6. Diagram showing relative plume size (plan view) predicted by the numeric random-walk model. Consult the text for the assumptions implicit in these simulations. The contour interval is 5 particles per unit volume. Note the change in horizontal scale for the dimensions of the fill. The large black area indicates the source, not shown at 6 months to show concentration at the source of about 45 particles per unit volume.

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and remains on the project site, with maximum concentrations of contaminants approximately 50 percent of the initial concentrations at the source after 15 years (Table 3; Figure 6). With transport of the outer edge of the plume to a distance of less than 200 m from the edge of the disposal pit, the plume would not even reach the south pond in a 15-year period for the more probable case based on the geometric-mean hydraulic conductivity. The concentrations would almost certainly be lower than that predicted by the model because groundwater flows from the site in three directions, not one; boron is absorbed by plants and soils; and the source has not maintained a constant concentration of 104 ppm. More realistic and less conservative transport models will be developed once boron is detected in a downgradient well.

## Conclusions

A shallow, thin, unconfined groundwater flow system has developed in the base of the spoil and the more permeable bedrock units. Past mining has degraded groundwater quality and reclamation with coal-combustion residues at this site pose no risk to potable groundwater resources. This study suggests that for the more probable case, contaminants associated with the leachate generated by the coal-combustion residues on site would have little impact on groundwater quality.

Environmental studies will continue, including the installation of additional downgradient monitoring wells as well as monthly monitoring of hydraulic head and groundwater quality. Once contaminants from the residue leachate consistently reach downgradient wells, the contaminant transport model can be refined so that it more realistically simulates the leachate plume. Future modeling efforts will add the third dimension and include consideration of all flow velocity vectors in and around the reclaimed site.

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