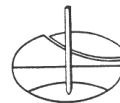
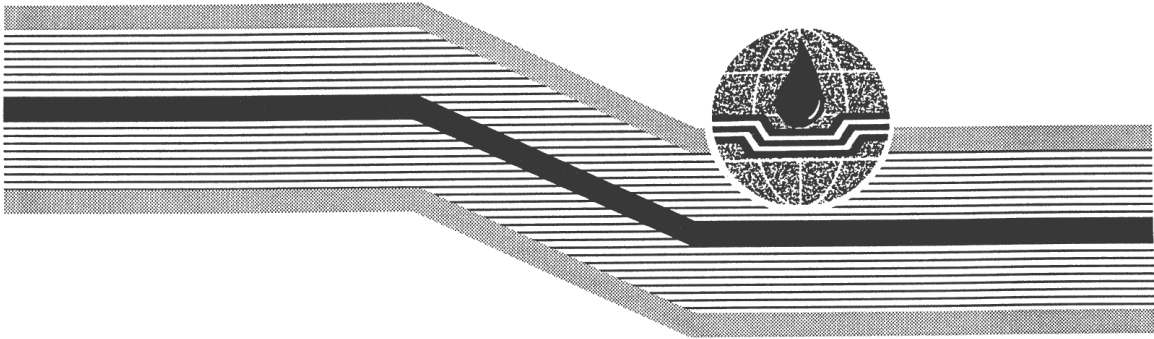


# First International Congress on Environmental Geotechnics

July 10-15, 1994  
Edmonton, Alberta  
Canada



## Computer Modeling to Define the Extent of Groundwater Contamination at a Coal Refuse Disposal Facility

**Krishna R. Reddy, Assistant Professor**

*Department of Civil Engineering, Mechanics & Metallurgy, University of Illinois, Chicago, Illinois, USA*

**Jeffrey C. Schuh, Vice President**

*Patrick Engineering Inc., Glen Ellyn, Illinois, USA*

### ABSTRACT

This paper presents the selection and construction of groundwater flow and contaminant transport models to assist in defining the extent of groundwater contamination so that a Groundwater Management Zone (GMZ) could be established at an existing coal mine facility in southern Illinois. The models will ultimately be used to determine an efficient extraction well system for the control and treatment of contaminated groundwater. The mine has been in operation since 1977 and has utilized groundwater and surface water in coal processing operations. The refuse resulting from the coal processing is disposed on site by constructing perimeter embankments with coarse refuse and then depositing fine refuse into the impoundment formed by the embankments. The uppermost aquifer has been impacted by leachate from the refuse piles and a GMZ needed to be established for groundwater control and treatment. Computer modeling of groundwater conditions was performed to assist in defining the extent of contamination and was used to determine locations for long term monitoring of groundwater conditions.

### Introduction

A coal mine, located in southern Illinois, has been in operation since 1977. The raw coal is processed on-site and then transported by trains to utility companies. Refuse (waste) generated from coal processing operations is disposed on-site at two areas known as Refuse Disposal Area No.1 (RDA-1) and Refuse Disposal Area No.2 (RDA-2). Refuse consists of two types: coarse refuse and fine refuse (slurry). The coarse refuse is transported in off road haul trucks while the fine refuse is conveyed through pipes which are directed to the disposal areas. The refuse is disposed by constructing perimeter embankments with coarse refuse and then depositing fine refuse into the impoundment formed by the embankments. The embankments are approximately 60 feet high. Drainage ditches and holding ponds along the periphery of the refuse disposal areas control stormwater runoff. The mine facility includes two artificial lakes, known as Fresh Water Lake (FWL) and Recirculation Lake (RCL). Clarified water from the refuse disposal areas and water from RDA perimeter drainage ditches and holding ponds is stored in the RCL. The remaining site drainage is directed into the FWL. Controlled discharges have been permitted from the FWL and RCL into the adjacent Grassy Branch. Figure 1 shows the locations of the refuse disposal areas, lakes, holding

ponds, Grassy Branch and Sugar Creek.

Water quality in the refuse impoundments, holding ponds, FWL, RCL and Grassy Branch has been monitored on a regular basis. Groundwater quality has been also monitored using a network of monitoring wells. The monitoring well data indicated that the groundwater within the uppermost aquifer has been impacted by the refuse disposal areas and other on-site sources (including the FWL and RCL). The groundwater quality (specifically concentrations of chloride, sulfate, total dissolved solids, iron and manganese) in some parts of the site exceed the regulatory maximum allowable values. In an attempt to reduce the degradation of groundwater, a remedial program consisting of three pumping wells was implemented in 1981. Figure 1 shows the locations of all monitoring wells at the project site as well as the pumping well locations.

In spite of the continued operation of the pumping wells, degradation of groundwater was observed in some of the monitoring wells. Because of increased groundwater contamination, the Illinois Environmental Protection Agency required that the extent of contamination be determined, a Groundwater Management Zone (GMZ) be defined, and a plan be developed and implemented to control and ultimately remediate the contaminated groundwater.

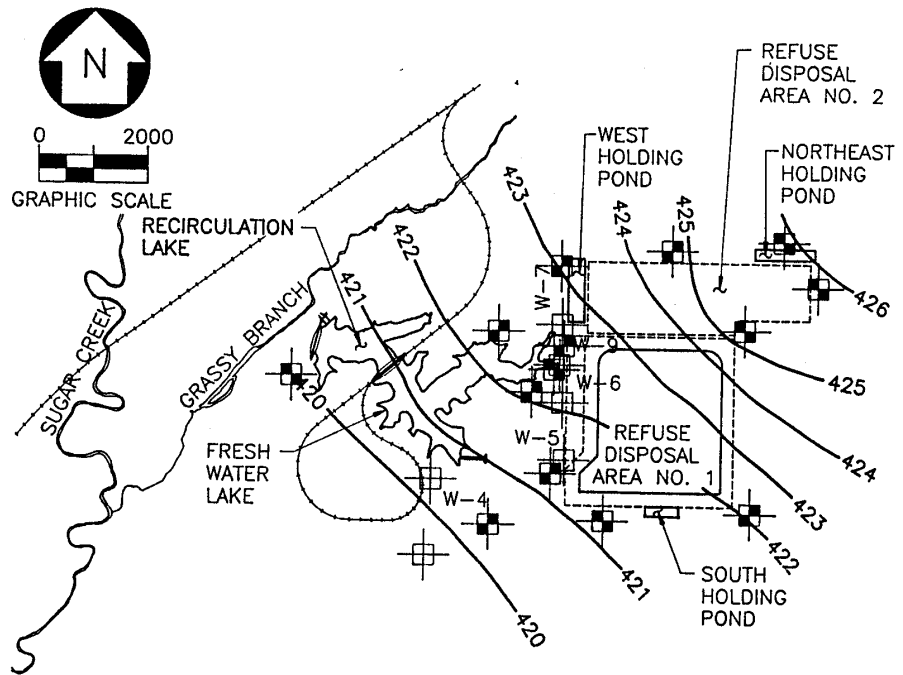


Figure 1. Site Features and Static Piezometric Surface Contour Map

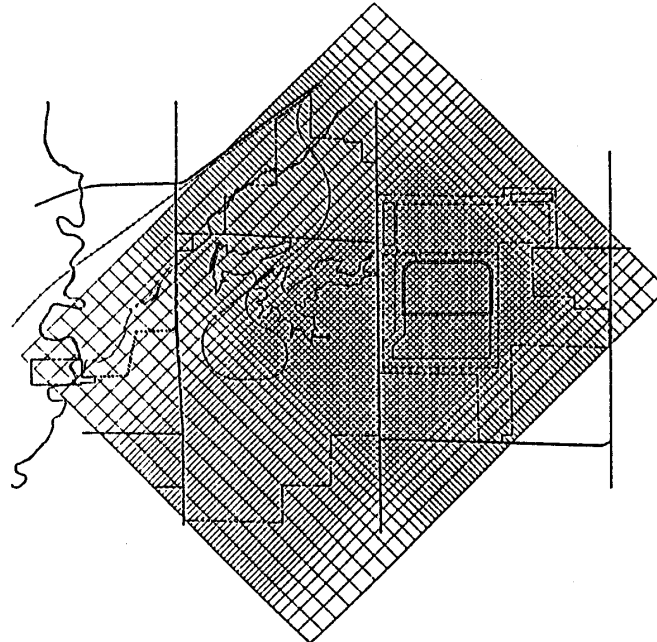


Figure 2. Model Grid

This paper briefly presents the site conditions including site hydrogeology and groundwater quality at the mine site. Details on modeling methodology, model calibration, and model results are then presented. The usefulness of the modeling to predict the plume location and the benefits of modeling in the determination of a GMZ are then discussed.

### Site Conditions

**Site Geology.** The site geology was defined using information from over 125 borings drilled at the site and published literature from Illinois State Geologic Survey. The site geology has been generalized into six geologic units denoted by Units A through F as shown in Table 1.

TABLE 1-- Summary of geologic units

Unit	Thickness (ft.)	Description
A	12-22	Silty clay to clayey silt
B	0-35	Sand with fine gravel
C	0-48	Silty clay
D	0-10	Sand or fine gravel
E	10-50	Shale
F	125-225	Sandstone

**Site Hydrogeology.** A limited number of borings drilled at the site were converted into water supply wells, monitoring wells or remediation wells. These wells were used to measure water levels and to perform aquifer tests. Based on this data, three aquifers are located within the project area. They are: (1) Pearl Sand Aquifer or Unit B, (2) Lower Sand Aquifer or Unit D, and (3) Trivoli Sandstone Aquifer or Unit F. The other units (Units A, C and E) are low permeable units and act as aquitards or acquicludes.

The Pearl Sand aquifer is the uppermost aquifer that has been affected by the mine operations. The aquifer exists under confined conditions, yields moderate to large amounts of water, and it is considered to be the major aquifer at the site. The other two aquifers have not been impacted by refuse leachate because Units C and E serve as hydraulic barriers to the downward flow of groundwater. Therefore, only groundwater flow within Units A and B were analyzed for the determination of the GMZ.

Based on laboratory triaxial tests, the vertical hydraulic conductivity of Unit A averaged 0.032 ft/day. Based on

pump tests, the transmissivity of the Pearl Sand aquifer (Unit B) ranged from 5760 ft<sup>2</sup>/day to 15700 ft<sup>2</sup>/day. The storativity of this unit ranged from 1.1x10<sup>-4</sup> to 6.7x10<sup>-2</sup>. Water level measurements were utilized to interpret the flow conditions within the Pearl Sand. Groundwater flow is generally in the northeast to southwest direction as shown in Figure 1.

**Groundwater Quality.** Water quality sampling and testing has been performed at monitoring wells, remediation wells and surface water monitoring locations since the mine opened. The parameters tested include chloride, sulfate, total dissolved solids (TDS), manganese, iron, iron bacteria, pH, dissolved oxygen, ammonia, nitrate (as N), total alkalinity, total acidity and total hardness. Water quality data suggested that the refuse disposal areas as well as the on-site lakes have impacted the water quality within the Pearl Sand aquifer.

### Modeling Methodology

Modeling was performed in an effort to simulate the leaching from the refuse disposal areas and leakage from the on-site lakes into the Pearl Sand aquifer. Calibrated models would be used to select new monitoring well locations for the physical determination of the GMZ. Models would also be used to evaluate groundwater collection and treatment options.

**Models Used.** The computer models used for this study were: (1) Modular Three-Dimensional Finite Difference Groundwater Flow Model, known as MODFLOW, developed at the United States Geologic Survey (USGS) by McDonald and Harbaugh in 1988, and (2) Modular Three-Dimensional Contaminant Transport Model, known as MT3D, developed with funding from the United States Environmental Protection Agency (USEPA) by Papadopoulos & Associates in 1990. MODFLOW simulates groundwater flow conditions, and MT3D simulates the contaminant transport (using the flow conditions determined by MODFLOW). Complete details on the selected models are available in the respective documentation manuals [1,2].

**Model Grid.** Both the MODFLOW and MT3D models are based on the finite difference method and require a grid system. The size and orientation of the grid system used for this study is shown in Figure 2. The grid was developed to encompass the entire mine facility. The grid spacing ranged from 125 feet near the refuse disposal areas and lakes to 500 feet at the model boundaries. The selected variable grid spacing provides higher resolution at the potential source areas (refuse disposal areas and the lakes), enabling the

model to simulate the conditions accurately in the areas of concern.

The orientation of the model grid was selected to simulate groundwater conditions with minimal effect from boundary conditions. The model size was limited to the project site to avoid excessive extrapolation of hydrogeologic data.

**Model Layers.** The purpose of this study was to model contaminant migration and dispersion from the refuse disposal areas, lakes and ponds through Unit A and into Unit B. As such, the physical and hydrologic properties of Units A and B were needed for modeling of the Pearl Sand aquifer. The thicknesses of Units A and B are variable at the site, and interpreted thickness contour maps were used in the models.

Only one layer representing the Pearl Sand aquifer (Unit B) was used in the model. The thickness and hydraulic conductivity of Unit A was incorporated as a conductance term. This representation was used because: (i) leakage through Unit A can be represented by general-head boundaries with known conductance values, and (ii) consideration of one layer instead of two layers is computationally efficient. This representation also allowed the incorporation of leachate seepage through the refuse disposal areas.

Because of the dynamics of the groundwater regime in areas where pumping wells are located, the Pearl Sand aquifer (Unit B) may locally change from confined to unconfined conditions. Also, the transmissivity of the aquifer is variable because of the variable thickness of the aquifer at the site. Based on these considerations, the aquifer was specified as Layer-type 3 [1].

**Model Boundaries.** Review of the available geologic and water level data indicates that the Pearl Sand (Unit B) aquifer is not in direct hydraulic communication with either creek located to the west and to the northwest of the site. No other hydrogeologic boundaries are located near the model boundaries. For the purpose of modeling, artificial (or distant) boundaries were utilized.

Based on groundwater level measurements in the existing wells, groundwater flow within the Pearl Sand aquifer occurs generally from northeast to southwest (Figure 1). While not shown on Figure 1, the groundwater flow is altered in the vicinity of the on-site pumping wells due to pumping operations.

For the groundwater flow model (MODFLOW), the northeast and southwest boundaries were set as specified head values to allow discharge from the model towards discharge zones to the southwest. The other two boundaries of the model were assumed to be no-flow boundaries based on the flow pattern (Figure 1). Based on historical water level measurements (1991-1993) in the monitoring wells, piezometric levels for the Pearl Sand fluctuate seasonally, with the change in water levels on the order of 2 to 3 feet. This fluctuation in water levels was accounted for in the model by specifying time-dependent constant head boundaries. Plots of water levels versus time for the upgradient wells were used in setting the northeast constant head boundary.

Historical water quality data were used to establish initial chemical concentrations in the Pearl Sand aquifer for the contaminant transport model (MT3D). The northeast and southwest boundaries were set as constant concentration boundaries at background groundwater concentrations. The other two boundaries (no-flow boundaries) were assumed to be no-mass flux boundaries.

**Sources.** The following sources were incorporated into the models: Refuse Disposal Area No.1, Refuse Disposal Area No.2, Fresh Water Lake, Recirculation Lake, West Holding Pond and Northeast Holding Pond (Figure 1). These sources were modeled as general-head boundary conditions. Conductance values for each model cell within the source areas were calculated using the following equation and were then input to the model.

$$C = K \frac{LB}{T} \quad (1)$$

where C=conductance (ft<sup>2</sup>/day), K=hydraulic conductivity of Unit A (ft/day), L and B=dimensions of model cell (feet), and T=thickness of Unit A (feet). In the refuse disposal areas, the thickness and hydraulic conductivity of both the coarse refuse and Unit A were used to calculate equivalent conductance values. The general-head and water quality for each source were specified based on measured data.

**Sinks.** Existing water supply and mitigation pumping wells at the site were included as sinks in the modeling. The wells considered in modeling were: W-4, W-5, W-6, W-7 and W-9. The locations of these wells are shown in Figure 1. The measured pumping rate for each well was averaged for each quarter and this average rate was input to the model.

**Recharge.** Recharge was specified in the model to simulate percolation from precipitation. The recharge rate was calculated using the recorded precipitation and temperature data, and estimated runoff and evapotranspiration rates.

**Evapotranspiration.** Evapotranspiration losses were modeled using the procedures described in the MODFLOW manual by specifying the maximum evapotranspiration rate and the extinction depth.

**Contaminant Constituents.** Chlorides, sulfates, total dissolved solids (TDS), total iron and manganese are the primary indicators of groundwater contamination at the site. The initial concentrations of chloride, sulfate, TDS, total iron and total manganese in the Pearl Sand aquifer (Unit B) used to establish the initial chemical concentrations were based on the fourth quarter 1991 groundwater quality data obtained for the existing monitoring wells within the study area.

#### Model Calibration

Because of continued waste disposal and other operational activities, transient hydrogeochemical conditions exist at the project site. Prior to calibration of the models for transient conditions, steady state conditions needed to be defined. Consequently, a steady state analysis was performed for the first quarter and the results were then used to calibrate the models for transient conditions for subsequent quarters.

The model calibration was initiated with time zero being the beginning of the first quarter of 1992. Since this time, complete data on mining activities as well as groundwater quality and pumping well operations was available for model construction. The models were calibrated using the data for the first quarter 1992 through the fourth quarter 1992.

A good match between the measured concentrations and predicted concentrations was observed at several monitoring well locations. However, poor predictions were made at a few locations. This may be attributed to several simplifications and assumptions of the site hydrogeochemical conditions. The assumptions included the following:

1. The Pearl Sand aquifer is assumed to be isotropic and homogeneous.
2. The vertical distribution of contaminant concentrations within the aquifer is neglected. The concentrations at any location represent the averaged conditions over the aquifer thickness.

3. The quarterly averaged conditions are simulated, therefore, the short term effects of intermittent pumping and waste disposal operations are not accounted for.
4. No attenuation (other than dispersion) of chemical parameters is assumed to occur within the aquifer.
5. Source concentrations are assumed to represent the breakthrough concentrations into the aquifer.
6. The Pearl Sand aquifer, a continuum geologic medium, has been represented by discrete cells, and the models have been simplified to represent the averaged conditions within each model cell.

#### Results and Discussion

The models as calibrated show that groundwater within the Pearl Sand aquifer is being impacted by seepage from all the on-site sources. The initial contamination observed at the site appears to have occurred from RDA-1 and the on-site lakes. Breakthrough concentrations from RDA-2 and the holding ponds appear to be starting to impact groundwater. RDA-1 will remain a potential source of contamination due to the large quantity of waste deposited in this area.

The models calibrated in this study were used to predict the extent of groundwater contamination in the Pearl Sand aquifer for the third quarter 1993. The predicted concentrations of chloride and TDS are shown in Figure 3.

The developed models represented the best estimate of contaminant plume movement within the aquifer. Because of the limited information available, it was not expected that the models would predict the exact location of the plume fringe. The sole purpose of the initial modeling was to provide guidance on the selection of new monitoring well locations and to provide a model which could be refined as more data is collected.

The use of computer models to predict the contaminant plume location proved to be beneficial in that monitoring well locations could be selected based on simulated site conditions rather than by judgement only. As computer modeling was ultimately needed to evaluate remediation options, construction of the models early in the groundwater evaluation allowed for the continued calibration of the models as additional data was collected. This approach to modeling hydrogeological conditions resulted in a model which accurately predicted the plume fringe and reduced the number of monitoring wells needed to define the GMZ.

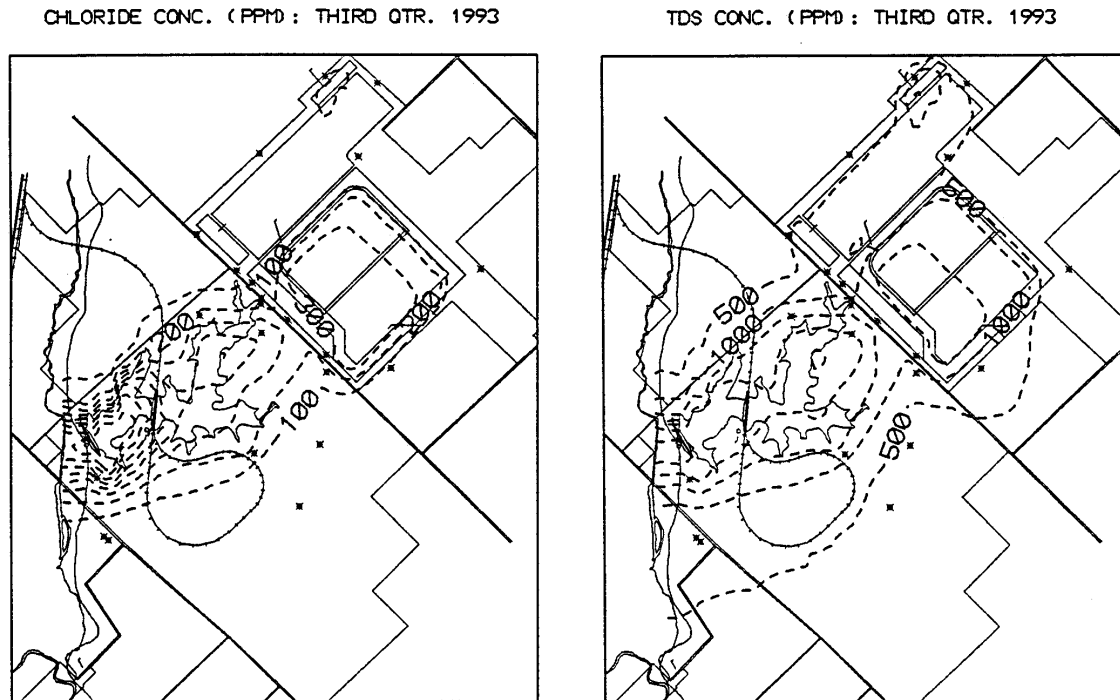


Figure 3. Model Predictions

### Summary

The available hydrogeochemical data has been used to construct a groundwater flow model (MODFLOW) and a contaminant transport model (MT3D) for a coal mine facility to determine the extent of contamination and to ultimately evaluate remediation options. The models were calibrated using historical groundwater quality data obtained for the last quarter of 1991 and all four quarters of 1992. The models were then used to predict the extent of groundwater contamination and to optimize the number of monitoring locations for long term monitoring of groundwater conditions.

### References

1. McDonald, M.G., and Harbaugh, A.W. (1988), "A Modular Three-Dimensional Finite Difference Ground-Water Flow Model," USGS TWRI, Chapter 6-A1, pp.586.
2. Zheng, C. (1992), "MT3D: A Three-Dimensional Transport Model," Version 1.8, S.S. Papadopoulos & Associates, Inc., Bethesda, Maryland.