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ENVIRONMENTAL RESEARCH BRIEF

INVESTIGATION OF FAILURE MECHANISMS AND MIGRATION OF INDUSTRIAL CHEMICALS AT WILSONVILLE, ILLINOIS

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Abstract

In late 1981, ground water contamination was discovered in a monitoring well at the Earthline disposal facility near Wilsonville, Illinois. This meant that organic chemicals had migrated at a rate of 100 to 1000 times the rate predicted when the site was given its permit in 1976. The Illinois State Geological Survey (ISGS) then conducted a 3-yr, multidisciplinary study to determine why the site failed to perform as predicted. Geology, hydrogeology, geochemistry, engineering geology, and x-ray mineralogy were disciplines used in the study of this site.

Postulated failure mechanisms included migration through previously undetermined (unmapped) permeable zones, subsidence of an underground mine, organic chemical/clay interactions, acid mine drainage/clay interactions, and trench cover settlement and erosion. The study concluded that the primary reason for the rapid migration was the presence of previously undetermined permeable zones that included fractured and jointed glacial till formations. The inaccurate predictions were caused by the use of laboratory-determined hydraulic conductivity values, which did not adequately measure the effects of fractures and joints in the transit time calculations. Field-measured hydraulic conductivity values were generally 10 to 1000 times greater than their laboratory measured counterparts, thus largely accounting for the discrepancy between predicted and actual migration rates in the transit time calculations. This however was compounded by the burial of liquid wastes and by trench covers that allowed excess infiltration to enter the trenches. Organic chemical/clay interactions may also have exacerbated the problem in areas where liquid organic wastes were buried.

This Research Brief was developed by the principal investigators and EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in the reports and publications listed at the end.

Introduction

Earthline Corporation, a subsidiary of SCA Services, Inc., began operating a 130-acre landfill near Wilsonville, Illinois, on November 15, 1976. The operation was a trench-and-fill procedure that relied on a clayey glacial till deposit native to the site for natural attenuation of any leachate. A compacted clay liner was reportedly used to supplement native till in at least one of the trenches. The company had applied for and received a permit from the Illinois Environmental Protection Agency (IEPA) to dispose of industrial and hazardous wastes at the site.

Several months after the landfill was in operation, the citizens of Wilsonville became alarmed at the disposal of hazardous wastes near their community. They filed suit to stop the disposal of wastes and to have them removed from the site. A lengthy court battle ensued, and Earthline continued to bury wastes. In 1981, the Illinois Supreme Court affirmed the 1978 trial court's ruling that the hazardous wastes buried in the 26 trenches (each 10 to 20 ft deep, 50 to 100 ft wide, and 175 to 400 ft long) at Wilsonville must be exhumed and removed from the site. SCA Services, Inc., announced in March 1982 that they were dropping further appeals and would comply with the court order. The preparation began in the summer of 1982, and the actual exhumation and removal process, begun on September 7, 1982, was expected to take approximately 4 yr. Earlier that year, in January 1982, the IEPA confirmed

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that organic pollutants had migrated as far as 50 ft from the trenches in a 3-yr period. The levels of volatile, organic priority pollutants found were reported by Johnson et al. (1983). This discovery was a separate issue from the court proceedings and exhumation order. The migration rates were 100 to 1000 times faster than predicted. Two obvious questions were posed: (1) why were these organic compounds migrating faster than predicted and (2) what are the implications to land disposal of similar wastes at other sites? This research project was designed to provide answers to these and many other questions regarding the efficacy of land disposal of hazardous wastes – particularly organic liquids.

The study of the site was a cooperative effort between several agencies and the site owner. The U.S. Environmental Protection Agency supplied a major part of the funding through a cooperative agreement with the ISGS, whose personnel performed a majority of the work. The IEPA provided a drill rig and crew for the field studies and performed organic analyses on soil and water samples from the site. The site owner, SCA Services, Inc., provided access to the site, safety training, and a substantial amount of the materials for construction of the monitoring wells. Waste Management, Inc., which later took over ownership of the site, continued to cooperate with the study and additionally provided some analytical support for monitoring well samples.

Objectives

To answer the two major research questions, the scope of work needed to include studies of several aspects of site behavior.

1. Site characterization – detailed descriptions of geologic materials, geomorphology, and; hydrogeology; comparison of field and laboratory measurements of hydraulic conductivity; significance of fracture flow.
2. Groundwater quality – distribution of organic chemicals across the site, sampling methodology for volatile organic compounds in fine-grained sediments.
3. Organic chemical/clay interactions-laboratory studies to determine effects of organic chemicals on permeability and pore structure of clay soils.
4. Gob pile effects-effects of acidity and high inorganic salt content of leachate from adjacent coal refuse pile (gob pile) on the trench materials.
5. Trench cover studies-observations of condition of trench covers, differential settlement, and mine subsidence.
6. Condition of drums and wastes-photographic documentation of effects of leachate on drums.

A multidisciplinary/multiagency approach was adopted early in the planning of this project. Cooperation with the site operators improved access to the site and reduced legal problems. Consolidation of efforts also reduced the number of borings, samples, and analyses required.

Site Characterization

Geology

An extensive geologic investigation and description of the site was carried out to place this site in the proper regional geologic framework and to collect sufficient baseline data for extrapolating the results from this investigation to other sites. The geologic characterization was carried out by four principal means: (1) examination of all previously gathered data and information, (2) investigation of outcrops and exposures at and in the vicinity of the site, (3) study of the trench walls themselves and backhoe pits at selected locations on and around the site, and (4) study of drill hole samples collected on and around the site. The location of the drill hole samples coincides with well nests and profiles shown on the site map (Figure 1).

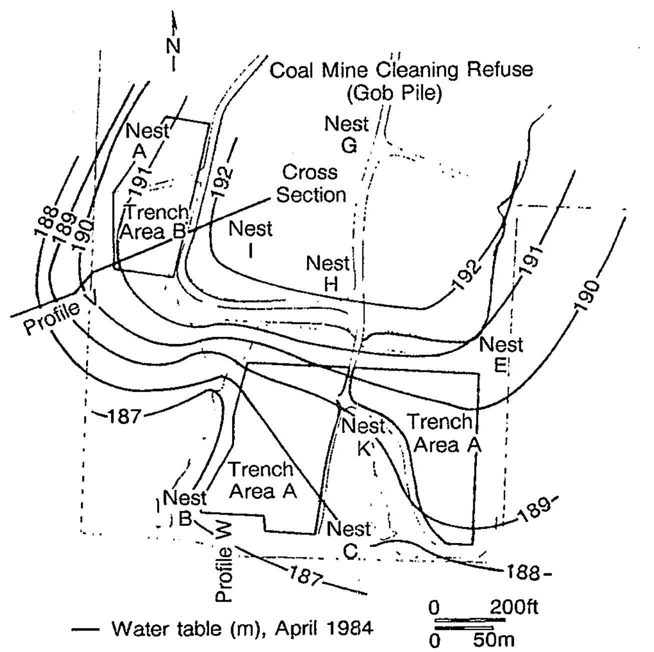

Figure 1. Map showing water table elevation (m) in April, 1984; locations of trenches, wells and cross section.

A detailed geologic description of the site was presented by Follmer (1984); a cross section is given in Figure 2 following the orientation shown in Figure 1.

The first unit encountered at the land surface is the modern soil developed in the Peoria Loess. It is orange-brown in color and is variable in thickness across the site. The loess itself is a windblown, clayey silt. The combined thickness of the Peoria Loess and modern soil ranges from 1 ft to 4 ft. Beneath the Peoria Loess is the Roxana Silt with the Farmdale Soil developed at the top of the silt. This silt, which has a higher sand content than the Peoria Loess, is 1 ft to 3-ft thick. Underlying the loess is the Vandalia Till, which has three phases: an upper, brown, stiff weathered zone, a brown, brittle weathered zone, and a gray unweathered zone. An ancient soil, the Sangamon paleosol, is developed in the upper portion of the till and varies from 8 ft to 12 ft in thickness at the site. Discontinuous sand lenses are found widely scattered throughout the Vandalia Till, but are more common at the base of the unit. The Vandalia Till, below the Sangamon Soil, typically varies in thickness from 5 ft to 20 ft. This till overlies an older till of the Banner Formation (Follmer, 1984). The thickness of this formation is unknown at most locations, since few borings penetrated it completely. One boring, at Nest 1, encountered nearly 50 ft of the Banner Formation.

An investigation designed to detect chemical and mineralogical effects in Pleistocene deposits by the overlying gob pile led to the observation of mixed-layer kaolinite/smectite (K/S) in the Sangamon paleosol. This clay mineral is an indicator of weathering in well-drained soils. Its irregular distribution suggests a complex pattern of well-drained and poorly drained soils during the Sangamon interval. It is probable that permeability and degree of cracking in the paleosol also vary with the paleodrainage and/or paleotopography. No alteration of feldspar to kaolinite was observed.

Hydrology

Hydrogeologic and geochemical investigations of the site were carried out using borings for installation of 11 piezometer nests, nine monitoring well nests and two well profiles (Figure. 1). Piezometer nests included three to six piezometers, whereas well nests contained two to four wells. Eight to ten wells were included in well profiles. Details of piezometer construction are presented in Herzog and Morse (1986) and Griffin et al. (1984). These piezometers were initially installed for in-situ hydraulic conductivity tests at the various depths of the piezometers. Later these piezometers were used to establish the long-term piezometric surface and, in turn, the hydraulic gradient and flow across the site. Core samples from these borings were used for chemical analysis. The chemistry of the water was not analyzed because of interference caused by the water added during the hydraulic conductivity slug tests. Slug tests were analyzed by three methods: Cooper et al. (1967), with additional type curves by Papadopulos et al. (1973); Nguyen and Pinder (1984); and Hvorslev (1951). These tests are discussed in detail in Herzog and Morse (1986). Results from these slug tests are given in Table 1.

Vertical holes were used to measure hydraulic conductivity in the horizontal direction, and angle holes at separate locations to measure hydraulic conductivity in the vertical direction. Three nests, containing three to four holes per nest were drilled on a 45° angle to intersect possible vertical fractures. In-situ hydraulic conductivity measurements were carried out; these results are also presented in Table 1.

Differences between vertical and horizontal hydraulic conductivity ranged from near agreement for a soft ablation zone to more than a factor of 10 in the unaltered basal Vandalia. The higher ratios in the basal Vandalia till are believed due to joints in the till that were observed to have a predominately vertical orientation. Vertical joints were observed in nearly all exposures of the till, in backhoe trenches on the site, and in the continuous cores collected from angle-hole drilling. These joints were common in the Sangamon Soil and decreased in number with depth.

The field-determined, hydraulic conductivity values were consistent between methods (Herzog and Morse, in press). Although not all piezometers could be reasonably analyzed using all three slug test methods, all could be analyzed by at least one method. These values are 10 to 1000 times greater than the laboratory-determined values (Griffin et. al., 1984; Herzog, and Morse, 1986). These differences are believed due to the discontinuous joints present in the tills and to scale effects.

A separate set of monitoring wells was constructed for water quality samples. Hydraulic conductivity was measured on the monitoring wells during development with the use of the recovery test as described by Todd (1980). These results are also given in Table 1. Recovery test results were generally higher than were slug test results. This is believed to be the result of an attempt to locate the monitoring wells in the more permeable zones.

ISGS monitoring well piezometers and SCA monitoring wells were used to measure the potentiometric surface in each zone. The water table is shown in Figure 1. Potentiometric surfaces of deeper zones showed the same general pattern with lower water levels, indicating that the zones are connected and the vertical gradient is downward. Figure 1 also shows the influence of the gob pile on groundwater flow at the site; groundwater flows radially outward from the gob pile.

Geochemistry

Sampling Protocol

As part of the groundwater sampling program, time-series samples were analyzed to help establish a protocol for sampling wells finished in fine-grained sediments. These tests, described more fully in Griffin et al. (1985), showed dramatic changes in concentration with time after purging. Most volatile organic compounds were found in their lowest concentration before purging and their greatest concentration after 2 hr to 8 hr of recharge. Additional research is needed however to verify the trends observed during this series of experiments.

Contaminant Distribution

Organic compounds were analyzed both from soil samples and from monitoring wells. The soil samples were collected as the bore holes for placement of the monitoring wells were drilled. As reported by Griffin et al. (1984), the highest concentrations of organic chemicals were found in the Vandalia Till ablation and weathered basal zones over most of the site. At nest V, the zone of highest contamination was the weathered basal Vandalia Till. These zones have higher hydraulic conductivities than both the overlying and underlying zones, as can be seen in Table 1.

Monitoring well results indicated that organic compounds were also found in the unweathered Vandalia Till. A typical contaminant distribution pattern with trichlorethylene used as an example, is shown in Figure 2. The highest levels of contamination on the site were found on the southwest corner of French Area A, at nests W1 and B, in the unaltered basal Vandalia, where endrin and dieldrin were

Table 1. Geometric Means of Field Hydraulic Conductivity Data

Material	Orientation	Slug tests (cm/s)			
		Cooper et al. method	Nguyen & Pinder	Hvorslev method	Recovery test
Peoria Loess/gob contact	Vertical				4.8×10^{-5}
Vandalia Till ablation zone–soft,clayey	Vertical 45° angle	1.3×10^{-7}	1.2×20^{-7} 6.4×10^{-7}	1.2×10^{-7} 4.3×10^{-7}	2.0×10^{-6}
Vandalia Till ablation zone–soft, mushy	Vertical 45°angle	3.8×10^{-5} 7.5×10^{-5}	1.9×10^{-5} 2.4×10^{-5}	1.2×10^{-7} 1.2×10^{-5}	1.6×10^{-5}
Base of ablation zone/top of altered Vandalia Till	Vertical				1.3×10^{-6}
Basal Vandalia Till–altered, jointed	Vertical 45° angle	1.2×10^{-6} 8.5×10^{-6}	2.3×10^{-6} 1.2×10^{-5}	8.4×10^{-7} 3.0×10^{-6}	4.0×10^{-6}
Basal Vandalia Till–unaltered	Vertical 45°angle	8.4×10^{-7} 5.7×10^{-7}	6.5×10^{-8} 9.4×10^{-7}	3.9×10^{-8} 8.0×10^{-7}	6.8×10^{-7}
Vandalia Till/Banner Formation Contact	Vertical				9.9×10^{-7}
Banner Formation/bedrock contact	Vertical		1.1×10^{-7}	2.8×10^{-6}	1.7×10^{-7}

present in concentrations greater than 1%. High levels of contamination in the unaltered Vandalia suggest that contaminants are moving downward through sand lenses and interconnected joints.

Organic Chemical/Clay Interactions

X-Ray Diffraction Studies

To establish a procedure for rapidly screening chemical effects on clay liners and covers, a study was done of changes in interplanar spacing of smectite in a sodium bentonite gel caused by different chemicals. The purpose of this research was to study the mechanisms involved in organic chemical/clay interactions. It was not meant to be site-specific to Wilsonville.

X-ray diffraction (XRD) was used to rapidly determine changes in basal interplaner spacing (001). A smectite gel in demineralized water has an (001) spacing of 100 to 150+ A. Many chemicals induce a collapse of the (001) spacing to 12 to 20 A. This collapse is associated with flocculation and crack formation in the gel, which, if occurring in the field, could result in large increases in permeability of a clay barrier. Past studies had suggested that the effects of chemicals on a smectite gel would be similar to the effects on nonswelling colloidal particles, although the magnitude of permeability change should be much less.

The XRD study confirmed estimates of the type of changes that occur. It was found that salts, alcohols, and several other chemicals that were miscible in water caused rapid collapse, flocculation, and crack formation in the bentonite gel. High concentrations of sodium collapsed smectite to 17 A as compared with 19A when saturated with calcium ions. Calcium replacement usually causes collapse. Expansion of smectite by organic chemicals is known to be roughly proportional to their dielectric constants. Unfortunately, only compounds miscible in water could be studied by this technique, and many of the problem chemicals at Wilsonville and other hazardous waste sites are mostly immiscible in water.

In summary, water, acetone, and various dispersants cause smectite to expand and seal clay liners. Most organic chemicals, metal cations with a charge above +1, and high levels of univalent ions cause collapse of the smectite with flocculation and cracking. These results indicate that non-expanding clay minerals might provide a better barrier to waste migration, especially if these liner materials are locally available and could be obtained at low enough cost to produce a significantly thicker barrier.

Viscosity and Test Tube Studies

Because the XRD experiments were limited by the types of chemicals that could be evaluated, a series of experiments were designed to see if viscosity measurements and/or change in gel structure in a sealed test tube could be used to rapidly screen new chemicals and mixtures of chemicals for their effect on liner integrity. The viscosity tests were run on sodium smectite gels, and XRD determinations were made before the samples were sealed in test tubes for still further observation.

Results matched very well with earlier XRD studies. It was again impossible to perform meaningful tests on immiscible chemicals. An attempt was also made to use acetone as an immiscibility "bridge," but the approach was not successful.

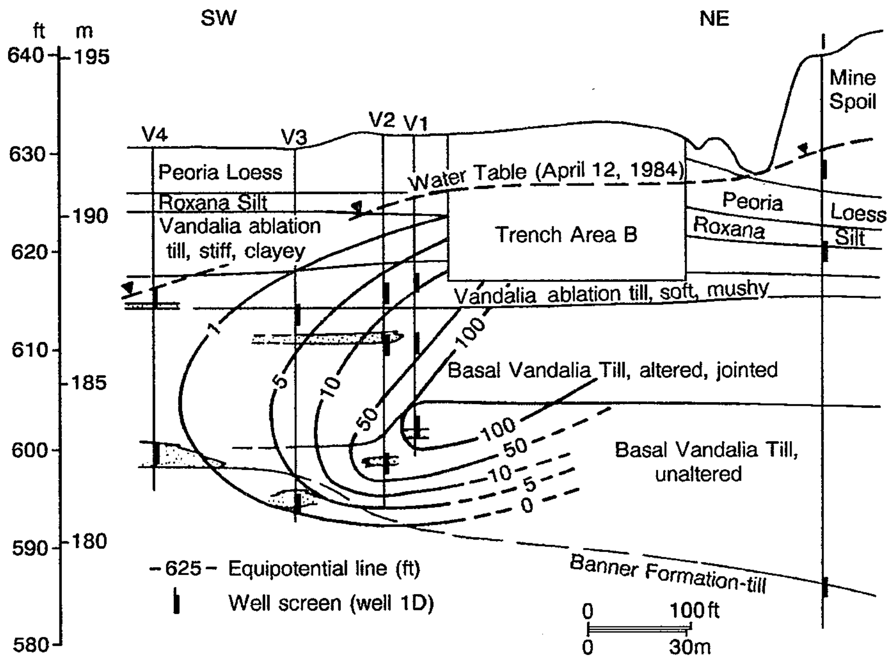

Figure 2. **Cross from Profile V through Trench Area B to the gob pile showing distribution and trichlorethylene (ppb) in groundwater, September 1984.**

A viscosity decrease, flocculation, crack formation, and (001) collapse were all closely correlated.

Future work should include more attention to partitioning coefficients for immiscible chemicals. After the degree of chemical adsorption on a water-wetted clay surface is determined, other tests should be made to determine the effect on liner integrity. More effort should be devoted to evaluate locally available clays for use as clay barriers and to compare those materials with bentonite. A study of rate of loss of water-immiscible wastes from organophillic adsorbent clays is also needed to estimate waste migration. Finally, both hydrophilic and organophilic systems need to be studied with complex mixtures of chemicals under realistic field conditions.

Gob Pile Effects

A study of the gob pile (coal cleaning refuse) was performed to determine if acid mine drainage increased the rate of contaminant migration. Measurements of soil pH were taken at increments of approximately 1 ft at Nest I. Values of pH in the gob ranged from 1.85 to 2.40, with the lower values occurring at the bottom of the gob pile. The pH measurement immediately below the gob pile was 3.25. Within 8 ft of the bottom of the gob pile, pH values were greater than 7 and between 7 and 9 for the remainder of the stratigraphic column.

Measurements of pH were also made at monitoring wells in Nest A and Profiles V and W. All water samples had pH values between 6 and 7. It was concluded that the effect of acid mine drainage was highly localized and did not affect chemical migration in the trenches at the site.

Trench Cover Studies

Cover Condition

The condition of the covers was examined as the covers were removed to determine the effect of surface and internal erosion. Investigative techniques included photo-interpretation, remote sensing, and soil erosivity testing (Stohr et al., 1985).

Depressions and sinkholes in the trench covers were found by field inspection, supplemented by interpretation of large scale aerial photography. Most severe depressions occurred over trenches that extended to nearby contaminated monitoring wells (Stohr et al., 1985). Not all contaminated monitoring wells were associated with depressions, however. Freely drained depressions were distinguished from water-holding depressions with the use of a post-sunset thermal infrared ground survey. Freely drained depressions were slightly warmer than the adjacent ground, whereas water-retaining depressions were relatively cooler.

Soil erosivity was tested using the pinhole techniques developed by Sherard et al. (1976) to determine the susceptibility of trench cover materials to piping. The qualitative results ranged between "unsusceptible" and "highly susceptible" to piping. A cover in French Area B, which contained sinkholes, included both severely erosive and very resistant soils. No depressions were found in French Area A and its cover was moderately resistant to piping (Stohr et al., 1987). This suggests that the pinhole test would be useful for selecting cover material.

Differential Settlement

Tilt plates and a precision (third-order) survey were used to monitor settlement, differential settlement, and tilt of some of the trench covers (Griffin et al., 1983). A "Tiltmeter" (manufactured by Slope Indicator Company*) recorded tilting measurements at points on 11 trench covers.

Multiple linear regression was employed to model the relationships between tilting plates and climatic variables (temperature and precipitation) for 3, 7, and 14 days before surveying. The model accounts for only 34% of the movement of the tilt plates.

Both temperature and precipitation, at days 3 and 14, however, correlated inversely with the tilt plate elevation data during the study period. This movement is believed to loosen the compacted soil thereby increasing void pace and pore size. The surface of the cover appears to be particularly vulnerable to these effects.

Mine Subsidence

Subsidence of an underground coal mine, located 300 ft below the site, was postulated to cause trench instability and, therefore, to increase rates of chemical migration.

Stereoscopic examination of historical aerial photographs showed no depressions adjacent to the landfill site. Tree canopies obscured the ground in some areas; however, no pattern of tilting trees was observed. A ground reconnaissance survey done before the exhumation activities found no surface depression or other indications of mine subsidence at the landfill site.

Monthly precision (3rd order) vertical surveys of deep settlement probes set at or below the bottom of the burial trenches were done to measure near-surface movements that indicate underground mine stability. Statistical analysis by Pearson correlation coefficients showed that all, except one, of the deep probes were highly correlated. The movement of the exception probe is believed to be due to slope instability, because of its proximity to a steep slope. Therefore, because no mine subsidence was present at the site, mine subsidence did not affect the rate of chemical migration.

Conditions of Drums and Wastes

As drums and other wastes were removed from the trenches, their condition was documented to help interpret the effects of the leachate on the drums and earth materials, the relative leachate strength, and drum life expectancy.

On three occasions, stereo photography was used to record trench investigations. A 2-ft aluminum cube assembled on site was used for interior orientation of the photography (Stohr, 1983). Photographic observations of drums and other waste containers were made periodically during the landfill exhumation. Observations and photographs were not made systematically, however.

Results from one study of inclination of drums in one trench indicated that they varied from 0° to 32° from the vertical as measured from a photograph with a level and plum aluminum cube atop the drums. Void space between the drums was calculated to range from 17% to 38% of the trench volume. The condition of the exhumed drums and wastes varied greatly: the inclination of drums varied from 0° to 90° from vertical and the condition of the waste was from good to highly degraded. The good condition of some drums (paint intact, drums undeformed, and sacks of herbicide intact) suggests that the longevity of a waste container in a landfill depends on its original condition, handling, contents, and the composition of fluids that surround it. During the excavation of trench 24, drums buried 3 yr earlier, sitting in an unknown orange-brown liquid, had intact paint (although some showed surface corrosion).

Conclusions

The primary reason that the Wilsonville industrial waste disposal site failed to perform as predicted was that the earth materials had higher hydraulic conductivity values than the original tests indicated. The original predictions were based on laboratory-determined values of hydraulic conductivity, which were confirmed by this study. Field-determined values of horizontal hydraulic conductivity, however, were 10 to 1000 times greater than laboratory-determined values. In addition, the original investigation did not recognize the importance of vertical joints and disconnected sand lenses. These joints cause the vertical hydraulic conductivity to be up to 10 times greater than the horizontal value. Joints and sand lenses also presented preferential pathways for downward movement of chemicals at some locations in and around the site.

Rates of chemical migration may also have been enhanced by differential settlement and reactions of organic chemicals with clay. Highly erodible earth materials allowed freely draining depressions to develop in the trench covers, and thus permitted surface water to enter the trenches, interact with, the waste and increase groundwater gradients out of the trenches.

The highest levels of contamination found at Nest B and Profile W are immediately downgradient of an area where large quantities of liquid wastes were buried. Interactions between these chemicals and the clay may have opened joints, and increased downward flow. This mechanism does not appear to be significant elsewhere on the site.

Although the site was not affected by the acid mine drainage or subsidence, the coal refuse pile did create a groundwater mound that affected the local flow direction and gradients in the shallow groundwater flow system.

This Research Brief and the articles by Follmer (1984), Griffin et al. (1983, 1984, 1985), Herzog et al. (1989), Herzog and Morse (1986, and in press), Johnson et al. (1983), Stohr (1983), and Stohr et al. (1985 and 1987) were submitted by the Illinois State Geological Survey in partial fulfillment of Cooperative Agreement CR810442 under the sponsorship of CR810442 under the sponsorship of the U.S. Environmental Protection Agency. The Principal Investigator was Dr.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use..

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