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Waste and Cost Reduction Using Dual Wall Reverse Circulation Drilling with Multi-Level Groundwater Sampling for Contaminant Plume Delineation

1. INTRODUCTION

This paper describes the drilling and sampling methods used to delineate a groundwater contaminant plume at the Paducah Gaseous Diffusion Plant (PGDP), Paducah, Kentucky, during the Groundwater Monitoring Phase IV characterization. The project was unique in that it relied upon dual wall reverse circulation (DWRC) drilling instead of the traditional hollow stem auger method. The DWRC drilling method was used to drill 47 borings averaging about 150 ft deep and one boring 350 ft deep. The method was selected based on the following reported characteristics:

- provides a fast and efficient method for drilling exploratory borings while allowing continuous monitoring of formation samples;
- significantly reduces the possibility of cross contamination within the borehole because there is no annular space between the drill string and the borehole wall;
- allows discrete water samples to be collected from within the inner tube of the drill string;
- produces cutting volumes near theoretical hole size and simplifies handling because the cuttings are deposited directly into drums;
- allows geophysical logging to be conducted inside the inner drill tube; and
- permits pressure grouting of the borehole as the drill string is withdrawn, thus preventing later cross contamination between water-bearing zones.

The strengths and weaknesses of the method are discussed within this paper. A comparison of the estimated project duration and costs between performing the investigation using traditional hollow stem auger boring methods, using permanent well clusters, and using the DWRC drilling method with multi-level groundwater sampling clearly shows that the DWRC drilling method is the most cost-effective and efficient approach for this site.

1.1 Background

A U.S. Department of Energy (DOE) facility located in western Kentucky, PGDP enriches uranium for commercial nuclear reactors using the gaseous diffusion process. Past industrial and construction activities at PGDP have resulted in contamination of groundwater in the shallowest aquifer, the regional gravel aquifer (RGA). The northeast plume at PGDP, groundwater contaminated with trichloroethene (TCE) and ^{99}Tc, was identified during a two-phased site investigation

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conducted from 1989 to 1991. The investigation reported on here was performed in 1994 to further delineate the horizontal and vertical extent of the northeast plume. The plume appears to emanate from the eastern half of the plant site and extends approximately 2.5 miles northeast, with an estimated areal extent of 1.2 $miles^2$. Prior to this investigation, 17 wells in 11 clusters had penetrated the plume, mainly around the edges.

1.2 Purpose

In spite of previous investigations, no definitive source(s) of contamination had been determined for the northeast plume nor had the boundaries of the plume been determined, either horizontally or vertically. Investigators suspected that the northeast plume was formed by the coalescence of several smaller plumes emanating from different sources. It was postulated that these individual plumes had "hot spots" and were possibly separated from one another by areas of clean, uncontaminated groundwater. In addition, the presence or absence of contamination in the deeper aquifer system, the McNairy Formation, had not been determined. Thus, the objectives of the investigation were to: 1) identify possible sources of contamination for the northeast plume, 2) describe the hydrologic interaction of the upper McNairy Formation with the overlying RGA, 3) characterize the vertical and horizontal extent of contamination, and 4) locate contaminant hot spots.

2. GEOLOGY

The subsurface at PGDP consists of Cretaceous, Tertiary, and Quaternary sediments unconformably overlying Paleozoic (Mississippian) bedrock (Clausen et al. 1992). Immediately overlying Mississippian bedrock at PGDP is the Upper Cretaceous McNairy Formation. The Paleocene Porters Creek Clay occurs in southern portions of the site, increasing in thickness southward. The Porters Creek Clay subcrops along a buried terrace slope that extends east-west across the site. Eocene sediments overlie the Porters Creek Clay in the extreme southern portion of the DOE reservation.

The base of the Miocene, Pliocene, and Pleistocene continental deposits represents a nonconformity. The sequence of Pleistocene continental deposits represents valley fill, the base of which exhibits steps or terraces. Investigators at the site have subdivided the continental deposits into a lower unit (gravel facies) and an upper unit (clay facies). Thicker deposits of lower gravel facies, up to 50 ft in thickness, exist in deeper scour channels of the ancestral Tennessee River and form the RGA. The thicker deposits trend east-west across the site and pinch out against the terrace slope under the southern end of PGDP.

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Loess overlies the continental deposits throughout the site and is difficult to distinguish from the underlying lacustrine sediments. The Groundwater Investigation Phase III project report provides more detail of site geology (Clausen et al. 1992).

3. FIELD ACTIVITIES

3.1 Scope

Field activities completed for this project included drilling soil borings, collecting soil cuttings for lithologic description and archival, collecting groundwater samples for field screening and laboratory analysis, collecting borehole geophysical data, abandoning boreholes, dewatering drill cuttings, and managing investigative derived wastes (IDW).

A subcontractor was responsible for drilling the required soil borings, collecting soil samples, geophysical logging of the borings, and providing a waste separation system for dewatering drill cuttings. PGDP Environmental Restoration (ER) personnel collected the groundwater samples, and Oak Ridge National Laboratory, Grand Junction, Colorado (ORNL/GJ), personnel supervised the drilling and sampling, prepared lithologic logs, performed health and safety monitoring, operated the field analytical laboratory, and managed IDW.

3.2 Drilling Method

The DWRC drilling system consisted of two concentric strings of pipe (Fig. 1). Top-head drive rotary power and a tricone bit were used to advance the drill string. An air compressor and diaphragm pump provided the drilling fluid as either air or air/water mist. The driller regulated the air/water mix depending on the water content of the interval being drilled; for instance, if the interval contained free water, then only air was injected. The air/water mist was forced down the annulus between the two pipe walls and exited around the bit into the borehole. This mist assisted with cutting the formation and returned through the center tube carrying the cuttings to the surface. The drilling rate averaged about 1.5 ft/min, and the cuttings return rate was about 60 ft/s. Thus, there was very little travel time for cuttings to reach the surface, and the geologist was able to detect lithologic breaks almost as soon as the bit encountered them. The drilling fluid only contacted the borehole wall at the bit, and since the bit outer diameter was slightly larger than the drill pipe (4⅝ in. vs 4¼ in.), the cuttings closed around the pipe, significantly reducing the potential for vertical cross contamination. At the surface, the cuttings were routed from the top head to a cyclone separator and discharged into 55-gal drums situated in a mud tank to contain any overflow.

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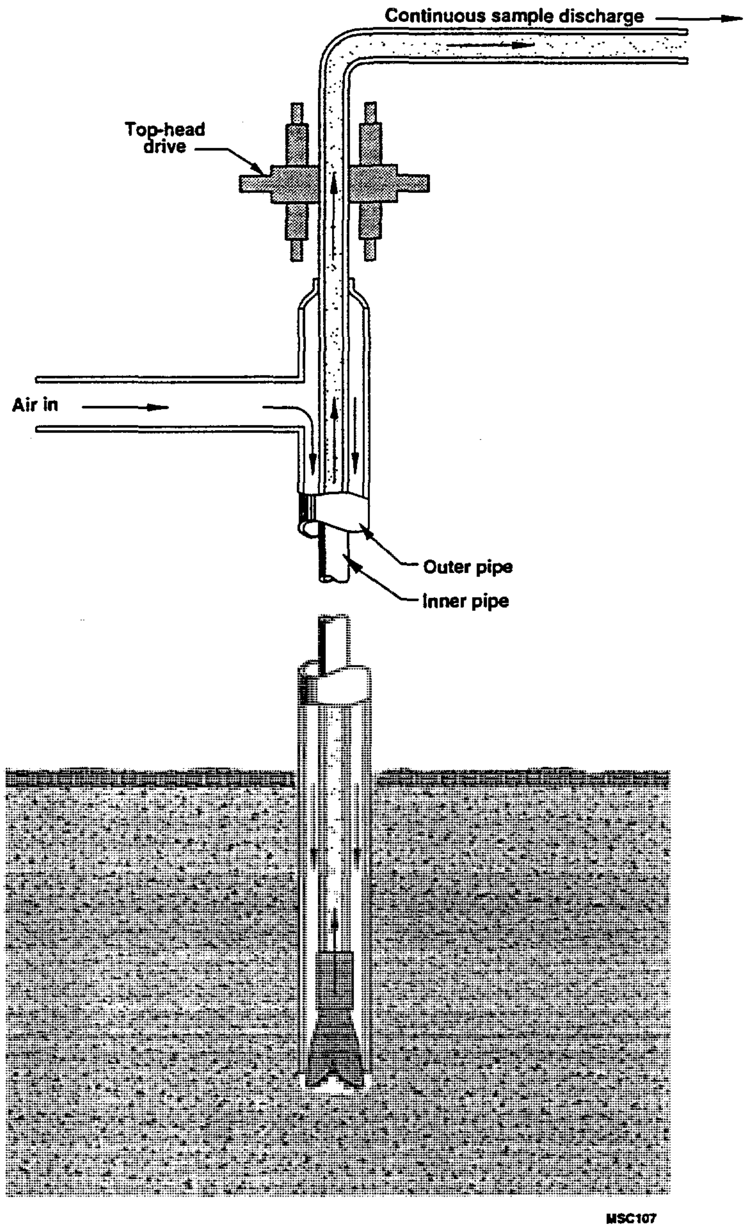

Fig. 1. DWRC drilling system.

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The general procedure followed in drilling and sampling the boreholes is described in the following paragraphs.

The borehole was advanced as described above to the first water sampling point, generally a sandy zone in the upper-continental recharge system or the top of the RGA. For the first few borings, overshot casing was advanced to within a few feet of the bit prior to water sampling as an additional means of isolating the interval to be sampled. Use of overshot casing required additional time for installation and cleaning and increased the amount of drilling spoils. Use of this casing was discontinued after a field experiment showed that there were essentially no differences in contaminant concentrations in water samples collected with or without the use of the overshot casing and that geophysical logs run inside the dual tube were very similar to those run with only the overshot casing in place.

Once the interval to be sampled was reached, excess water and cuttings were flushed from the system, and a bladder pump and packer assembly were lowered into the inner drill tube . The packer was inflated to seal off the interval to be sampled, which was then purged with the bladder pump. Water quality parameters were monitored during purging. The interval was considered purged once temperature, pH, and conductivity had stabilized for three consecutive readings at 5-min intervals. Midway through the project, micropurging was adopted, which reduced sampling time and purge water volumes (Kearl et al. 1994). Some intervals were sampled with a bailer instead of the pump-packer assembly if there was insufficient water for pumping or if flowing sands were encountered. Water sampling proved to be the most problematic portion of the investigation. The bladder pump and packer assembly often jammed in the drill rods due to heaving sand. Moreover, the bladder pumps required frequent replacement of Teflon® bladders, and the packers would not inflate and seal properly. Once micropurging was adopted, the packers were no longer needed and sampling time was reduced.

After sampling was completed for an interval, the sampling equipment was removed for decontamination, and drilling resumed until the next interval to be sampled was reached. Thus, the stop-and-go drilling and sampling was repeated as many as eight times per boring. Because water sampling generally required 1 to 2 h for each interval, it often took more than 12 h to complete all of the water sampling for a single boring.

After reaching the total depth to be drilled, all boreholes were logged for natural gamma radiation, and most were also logged with a neutron tool. The first few boreholes were logged with a density tool; however, this log was eliminated early in the project because the signal attenuation caused by the drill rods masked the formation response. The combination of gamma radiation and neutron logging provided excellent data and aided in correlating the borehole lithologic logs across the area.

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All boreholes were abandoned using a high-solids bentonite grout. The grout was mixed at the surface and pumped down the center of the drill string as the drill pipe was withdrawn, thus sealing off all water-bearing zones and preventing cross contamination of aquifers. The drill rig was then moved to the decontamination facility for cleaning, and the borehole was staked for future land surveying.

3.3 Waste Handling and Transport

Waste generation from the DWRC drilling method consistently exceeded pre-project estimates due to the air-lift pumping effect in water-bearing and heaving-sand zones. Additionally, when the air pressure was released to make pipe connections, the head differential between the unconsolidated formation and the inside of the drill string forced formation water up the inside of the drill string, producing extra water and cuttings. The slurry-like cuttings were also of a much different consistency than traditional drilling spoils generated from hollow stem auger drilling. The waste management department at PGDP was not equipped to handle waste in slurry form. All waste had to be separated into solid and liquid fractions. Following ineffective efforts to separate the liquid and solid fractions by flocculation and gravity settling, a centrifuge-based material separation system was procured. The reduction in IDW achieved by the system is shown in Table 1. After waste separation was completed, 237 drums of solid waste and 20,000 gal of water were turned over to PGDP waste management for processing and/or storage.

Table 1. Solid waste drum record

	No. of drums prior to waste separation	Average no. of drums per boring	No. of drums after waste separation	Average no. of drums per boring after separation
Drums from 47 borings, 150 ft deep	365	7.7	210	4.5
Drums from 1 boring 350 ft deep	48	48	27	27

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4. COMPARISON OF DWRC DRILLING WITH OTHER METHODS

This investigation used methods designed to expedite site characterization and define the vertical and horizontal extent of groundwater contamination in the northeast plume. Two traditional characterization methods used at PGDP on previous investigations are included here for comparison: (1) temporary borings drilled with hollow stem augers, and (2) clusters of permanent monitoring wells. Three cost components were compared: drilling, water sampling, and waste management (Table 2). The following observations result from comparison of the three methods.

- Project costs for the DWRC drilling method for a single boring (drilling, sampling, and waste management) were 50% of augered temporary boring costs and 23% of permanent monitoring well cluster costs.
- The average cost per water sample (for projects of equivalent scope) was 50% of augered temporary boring costs and 14% of permanent well cluster costs.
- Solid waste generation was 78% less than augered temporary borings and 88% less than permanent well clusters.
- Field time required was 68% less than for augered temporary borings and 87% less than for permanent well clusters.

Information and assumptions used in preparing the cost-comparison table were:

- Groundwater Monitoring Phase IV characterization borings were drilled to 150 ft (upper McNairy Formation), yielding five sets of discrete-depth water samples. The borings were logged with natural gamma radiation and neutron tools; lithologic samples were collected no less than every 5 ft.
- Traditional characterization borings were drilled to 150 ft, requiring 110 ft of 10-in.-diameter isolation casing. Continuous soil samples were collected during drilling, and five discrete-depth water samples were collected with direct-push sampling methods.
- Monitoring well clusters consisted of three permanent wells with 5-ft well screens set at 70, 90, and 140 ft (top and bottom of the RGA and upper McNairy Formation).

This comparison shows that the methods employed for this investigation were cost-effective, time-efficient, and yielded more data per dollars expended than previously employed conventional methods.

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Table 2. Project cost comparison, Phase IV method vs traditional methods (cost for 47 borings 150 ft deep)

	Temporary borings	Temporary borings	Permanent wells
	Phase IV method	Hollow stem auger	Hollow stem auger
Drilling cost	$404,200	$940,000	$2,646,100
Water sampling cost	$279,650	$317,250	$79,900
Waste management cost	$492,090	$1,104,500	$2,383,840
Total project cost	$1,175,940	$2,361,750	$5,109,840
Total water samples	235	235	141
Average cost/sample[a]	$5000	$10,050	$36,240
Total solid waste[b]	237 drums	1081 drums	2021 drums
Total liquid waste	51,000 gal	10,500 gal	151,000 gal
Total field days[c]	118 days	367 days	940 days

[a] The average cost per sample in this case was calculated by dividing the total project costs by the total number of samples. This number provides a means for comparing the relative cost of the sample data generated by the investigation using the three methods.

[b] The DWRC drilling method minimized solid waste generation, and the waste separation system further decreased the solid waste volume in a cost-effective manner.

[c] The number of field days is based on performing the work with one rig on site for the duration of the project. The DWRC drilling method is the fastest and most cost-effective of the three methods.

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5. SUMMARY

Overall, the use of DWRC drilling with multi-level sampling succeeded in obtaining the data needed to achieve project goals. This approach allowed the investigation to be directed based on near-real-time data. Use of downhole geophysical logging in conjunction with lithologic descriptions of borehole cuttings resulted in excellent correlation of the geology in the vicinity of the contaminant plume. The total volume of cuttings generated using the DWRC drilling method was less than what would have been produced by hollow stem augering but slightly more than pre-project estimates. The drilling rate was very rapid, often approaching 10 ft/min; however, frequent breaks to perform groundwater sampling resulted in a slower average drilling rate. The time required for groundwater sampling could be shortened by changing the sampling methodology and having additional equipment on standby. Analytical results indicate that the drilling method successfully isolated the various water-bearing zones and that no cross contamination resulted from the investigation.

6. REFERENCES

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