Geophysical and Immunoassay Techniques To Accelerate Hazardous Waste Site Remediation

SUSAN L. FERREL, ILEANA IVANCIU, AND JAMES SWEET

Remediation of soil can be a long, difficult, and costly process. The combination of innovative technology, strong project management, close regulatory liaison, and the integration of a variety of remedial options turned an unexpected drum burial site into the successful completion of a highway access ramp. Buried drums containing hazardous polychlorinated biphenyl (PCB) waste were encountered directly in the path of a proposed highway access ramp during construction activities. Geophysical techniques such as ground-penetrating radar and magnetometry were used to define the horizontal and vertical extents of buried drums and waste. Field-testing kits that exploit immunoassay techniques were used to screen and segregate the excavated PCB-contaminated soils quickly and inexpensively and minimize the number of required postexcavation samples. Analysis of duplicate soil samples confirmed the accuracy of the field-testing kits before and during the remedial activities. Buried waste and soils containing hazardous concentrations of PCBs were excavated, loaded into trucks, and transported to an approved Toxic Substance Control Act facility. Approximately 7256 Mg (8,000 tons) of the remaining nonhazardous soil was used on-site as fill during the ramp construction. Careful planning of the work and the establishment of an informal but highly effective partnering relationship among all participants resulted in a remedial project that proceeded expeditiously with significant cost savings for the client. Ultimately, the ramp was constructed and the highway was opened to the public on schedule.

The New Jersey Department of Transportation (NJDOT) was completing the construction of a long-anticipated, high-profile section of highway in northern New Jersey. During excavation activities related to building an access ramp, an undetermined number of buried drums were encountered directly in the path of the proposed ramp alignment. The buried drums effectively blocked the construction area, which consisted of a narrow wedge of land confined between a river and a protected wetland (Figure 1). Construction activities stopped so that a site investigation and subsequent remedial activities could be implemented. With construction already under way, design changes and change orders would have resulted in astronomical cost increases and months of delay. On-time construction of the ramp was important to NJDOT in order to open the highway to the public as planned.

Although virtually any form of remediation can be very costly, developing a well-planned, cost-effective strategy at the beginning of a cleanup project can minimize expenses that accumulate during the project. As much as possible was learned about the nature and extent of the contamination so that the remediation approach and equipment needs could be planned carefully to accommodate the limited site space and other requirements before the actual start of excavation, thus helping to avoid unexpected delays. The development of innovative solutions helped to achieve the client's ultimate goal of the project, which was to complete the cleanup as quickly as possible so that the ramp construction could be finished, thereby allowing the highway to be opened as scheduled.

REMEDIAL APPROACH

On the basis of information obtained during the initial site remediation activities, the buried waste consisted of drums in various stages of decomposition, drummed waste, and soils. The contents of the drums were homogeneous and compatible and consisted of a highly viscous, tar-like material with concentrations of polychlorinated biphenyl (PCB) above the federal Toxic Substance Control Act (TSCA) standard of 50 m/kg [parts per million (ppm)], which regulates PCB wastes as hazardous.

With the size of the work area limited by construction equipment, the adjacent river, and the protected wetland, site remediation had to be planned carefully. Geophysical surveys were used to define the extent of the buried drums. Information obtained on the hydrogeology and an initial ground-penetrating radar (GPR) survey indicated that the drums were buried in trenches within a 0.61-m (2-ft) layer located 1.83 m (6 ft) above the water table. A large amount of soil covered the buried drums and was probably unaffected by contamination. Samples were collected from these soils and were analyzed for PCB concentrations. The results indicated that soil mounded over the buried waste contained PCB concentrations below 2 ppm. From these results, a two-phase approach was developed for the remedial activities.

During Phase 1, approximately 9904 Mg (10,920 tons) of overburden material that was mounded over the buried drums was removed and used as fill during mainline highway construction. In Phase 2, the actual hazardous waste remediation, the decomposed drums and drummed waste were removed from the excavation, loaded directly in dump trucks, and taken to a specially constructed, TSCA-regulated landfill.

Field-testing kits employing immunoassay technology were used to segregate soil and minimize the number of postexcavation samples submitted for laboratory analysis. Postexcavation soil samples were collected at an approved frequency that was lower than typical regulatory agency requirements and submitted for laboratory analysis to validate the effectiveness of the PCB cleanup. A magnetometer (MAG) survey was conducted to ensure that no additional drums were present in the area of the excavation.

S. L. Ferrel and I. Ivanciu, BEM Systems, Inc., Eight Vreeland Road, Florham Park, N.J. 07932. J. Sweet, Bureau of Environmental Analysis, New Jersey Department of Transportation, Trenton, N.J.

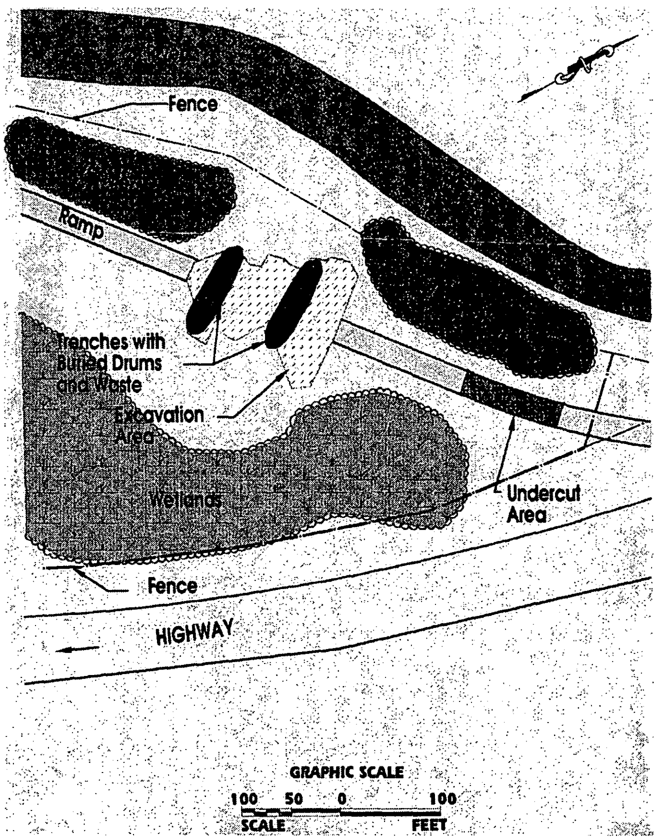

FIGURE 1 Site map.

The total excavation area was approximately 1148 m^2 (12,352 ft^2), with the average depth of excavation approximately 1.83 m (6 ft.) Soil sampling along the perimeter of the excavation confirmed that the contamination was localized and did not affect the wetlands or river sediments. A total of 3066 Mg (3,381 tons) of waste was excavated and transported off-site for disposal, and approximately 7256 Mg (8,000 tons) of nonhazardous soil was reused during construction.

The New Jersey Department of Environmental Protection did not require the remediation of surface soil (0 to 0.61 m) with PCB concentrations below 0.49 ppm on residential sites or up to 2 ppm on sites designated as industrial. For subsurface soils (below 0.61 m), soil with PCB concentrations up to 100 ppm could remain in place. However, if the soil is excavated and brought to the surface, it is judged a hazardous waste under TSCA if it contains PCB concentrations greater than 50 ppm; solids must be disposed of in a specially designed lined landfill, and liquids, in a specially licensed incinerator.

GEOPHYSICAL SURVEY

Background

Three geophysical techniques—MAG, electromagnetics (EM), and GPR—were used during the preliminary site investigation to assess the amount of buried waste and drums and to delineate their physical extent.

In MAG studies, magnetic anomalies are detected by measuring the magnetic field strength at evenly spaced points (a grid) throughout the area of interest. By plotting the location and magnetic field strength of each sampling point, a contour map can be generated to determine the location of anomalous areas.

EM methods use an alternating magnetic field generated by a coil at the ground surface, which penetrates the ground. A second coil, also at the surface, measures the earth's response. The response is proportionate to the electrical resistance of the soil's conductivity. The depth of the investigation is a function of the intercoil spacing. EM can detect differences in subsurface electromagnetic conductivity between two different layers.

GPR can provide high-quality data of near-surface conditions. GPR detects both metallic and nonmetallic targets. GPR instruments obtain subsurface information by inducing pulses of very high frequency electromagnetic energy into the ground. A portion of the induced pulse is reflected upward to the antenna from a reflection boundary and its return time is measured. The reflection boundary is the interface between materials having a measurable contrast in electrical properties. A cross section of the area of interest is generated by converting velocity and time-delay information.

Utilization

The performance of geophysical surveys at the site during various stages of the investigation enabled information about the subsurface to be collected without invasive techniques such as drilling or excavation. The geophysical surveys provided a mechanism to estimate accurately the soil volume and constituted a powerful tool in planning the excavation and remediation processes.

EM and MAG techniques were used to obtain an initial understanding of the subsurface conditions. An initial GPR survey established that a mound of soil, averaging 3.5 m (11.5 ft) high and about 0.1 ha (0.25 acre) in size, contained no debris. A subsequent GPR survey revealed that the waste and drums were buried within trenches oriented parallel to one another. The GPR survey indicated the presence of a single layer of drums within each trench buried under the mounded soil to a depth of about 1.83 m (6 ft) below the original ground surface.

A magnetometer survey conducted after the excavation of the buried drums and waste established that all the drums were removed and that no additional drums were present below the excavated area.

PCB ANALYSIS

At the onset of the remedial activities, PCB action levels had been negotiated with the regulatory agency having jurisdiction over the site. This was important since the latest guidance on soil remediation of PCB spills advocates a statistical sampling program with many samples, which would increase significantly the cost of analysis.

Standard turnaround time for PCB laboratory analysis (typically 3 to 4 weeks) would have delayed the remedial efforts and subsequently the construction schedule. Expedited turnaround time for laboratory analytical results was not a financially viable option. These problems were resolved by using what was then a little-known, innovative on-site analytical technology: enzyme-linked immunosorbent assay. Field tests using immunoassay techniques were approved by NJDEP for use at this site to aid in the segregation of the contaminated subsurface soil and to provide a means for reducing the number of postexcavation samples required to assess the effectiveness of the remediation.

Although the results of field-screening procedures typically are not accepted by regulatory agencies, including the Environmental

Protection Agency (EPA), as proper measurement of contamination for predisposal analysis or ultimate definition of contamination boundaries, the field analyses performed as part of this PCB remediation were approved and used as preliminary tests designed to help the technical personnel direct the assessment and cleanup activities.

Besides facilitating the segregation of the excavated soils, the use of field test kits also helped reduce the amount of postexcavation samples submitted for laboratory analysis. The 0.1-ha (0.25-acre) site may have required as many as 33 postexcavation samples, but the field test kits helped establish ahead of time the areas of the site where, based on the PCB concentration in the soil, the cleanup had proceeded to an acceptable level. Only 12 postexcavation samples were required for laboratory analysis to verify that contaminant concentrations above regulatory concern were not left behind. Duplicate samples were sent to the analytical laboratory to verify the results obtained by the field test kits.

Immunoassay testing techniques were selected because they possess a significant advantage over other field-screening tests in that the chemistry is PCB-specific. This feature precludes interference from other compounds and from native chlorine, such as that typically found in certain soils and other waste mixtures.

The manufacturer of the PCB field test kit was contacted concerning its application to this particular site. It was critical to know whether the field and soil conditions would allow for accurate and reproducible results. After the initial soil tests were conducted in the field and the duplicate samples that were sent to the laboratory revealed accurate results, the manufacturer provided a field test kit with PCB concentrations specific to the negotiated cleanup levels. The test kit provided results to determine if the concentration of PCBs in the sample was less than 2 ppm, greater than 2 ppm but less than 50 ppm, or greater than 50 ppm.

Immunoassay Overview

The PCB analysis approach used for this project employs a semiquantitative colorimetric method incorporating immunoassay technology, using tubes coated with antibodies that specifically detect PCBs (*1*). The test is "competitive," since the immobilized antibodies will bind to the PCB contaminant in a sample, the enzyme conjugate supplied with the test kit, or both in proportion to their relative concentrations. (The enzyme conjugate is prepared by covalent attachment of a PCB analog to the enzyme horseradish peroxidase.) After the used test tubes are washed to remove the sample solution, leaving behind the enzyme conjugate and PCB molecule immobilized by the antibodies, a chromogenic substrate that produces a vivid blue color in the presence of horseradish peroxidase is added to the test tubes. Color production is inversely proportional to the concentration of PCB contaminant in the sample: the more enzyme conjugate present, the faster the solution turns color and the darker it becomes. On the other hand, the more sample PCB molecules present, the fewer sites available for the enzyme conjugate and the lighter the solution. Therefore, the depth of the color determines the concentration range of the sample PCB solution.

Correlation of PCB Data by Field and Laboratory Analysis

To compare the results of PCB analysis by field and laboratory methods, six soil samples were analyzed for PCBs by both the field PCB test and by the gas chromatograph/electron capture detector method according to the EPA Contract Laboratory Program (Statement of Work for Organic Analysis, March 1990). Results of these analyses by both methods are given in Table 1. As shown in Table 1, the results obtained by the field-screening method for two samples are greater than those obtained by the laboratory method.

The scatter diagram of the relationship between PCB data by laboratory analysis and field screening is shown in Figure 2. When PCBs are undetected by the field-screening method, they are also not detected by the laboratory method. Higher values of PCBs by field screening are also associated with higher PCB values by laboratory method. A linear regression analysis was conducted by the StatView II program to see if there is a correlation between PCB laboratory data and field data presented in Table 1. As indicated in Table 2, the coefficient of correlation (r) was calculated to be 0.894 (a value of $+1$ or -1 stands for a perfect relationship and a value of 0 for no relationship), which is quite large. The coefficient of determination (r^2) is the square of the correlation coefficient. It is a number between 0 and 1 that shows how much of a relationship in correlation is due to the factors being compared. The closer the value of r^2 is to 1, the higher the degree of linearity of the points in the scatter diagram. For this correlation analysis, r^2 is determined to be 0.799. The adjusted r^2 is the square of the correlation coefficient adjusted for the small sample size and is calculated to be 0.749. It is the unbiased estimate of the population squared correlation coefficient. The root mean square residual is the square root of the mean square for residual of the analysis of variance (ANOVA) table (Table 2). It represents the standard deviation of the residuals, which are the errors of prediction, and is 2.415.

If

y = PCB lab data

and

x = PCB field data

Then the line of regression, expressed in the form of $y = bx + a$, is estimated to be

$$y = 0.22x - 0.912$$

where the slope (b) equals 0.22 and the intercept (a) equals -0.912.

The ANOVA procedure in linear regression analysis can be employed to test the significance of the slope b via an F-ratio. The ANOVA table (Table 2) represents a partition of the total sum of squares of the deviations into two parts: the sum of squares due to regression, and the sum of squares for residuals. The regression mean square is the variance of the fitted values, whereas the residual mean square is the variance of the residual values. The F-ratio, listed under F-test, is obtained as follows:

$$F\text{-ratio} = \frac{\text{regression mean square}}{\text{residual mean square}}$$

If the null hypothesis $b = 0$ is true, then there is no correlation between y (lab data) and x (field data).

However, the F-ratio is calculated to be 15.89 (Table 2) and is significant at $p = 0.016$. Therefore, the null hypothesis must be rejected. The slope b is significant by the ANOVA procedure.

The t-test was also used to test the significance of the slope b. The t-value is calculated to be 3.986. The level of significance (p) is 0.016, which is highly significant.

Although a small population was used for the correlation, there is a statistically significant correlation between PCB data by laboratory analysis and field screening.

TABLE 1 Data Correlation Between Laboratory and Field Analysis for PCBs

	PCB Concentration	
Sample ID	By Lab Analysis (mg/kg) *a*	By Field Analysis (mg/kg)
1	12.00	greater than 50
2	0.54	between 2 - 50 *b*
3	0.37	less than 2
4	<0.07	less than 2
5	5.20	between 2 - 50 *b*
6	<0.07	less than 2

a mg/kg = milligrams per kilogram = parts per million

b The mid-point concentration fo 26 mg/kg was used in linear regression analysis.

MANAGEMENT OF EXCAVATED SOIL

Before any excavation activities, NJDEP approved on-site segregation and reuse of the nonhazardous soil. According to the approved plan, soil with PCB concentrations between 2 and 50 ppm were encapsulated under the ramp itself, with the roadway serving as a cap, and any soils with concentrations above 50 ppm were landfilled according to TSCA requirements. The cleanest soils, with PCB concentrations no greater than 2 ppm, were placed in the roadway embankment under 0.61 m (2 ft) of clean soil. This approach was considered to involve no danger to public health and no further degradation of the environment while providing suitable fill for geotechnical applications. It enabled NJDOT to save substantially on the cost of fill while also saving the expense for the transport and disposal of moderately contaminated soils. For example, a portion of the excavation for the ramp was undercut (Figure 1) to accommodate some of the contaminated soil.

The soil generated during the excavation was segregated before reuse into potentially clean and potentially contaminated categories. The soil was staged in preselected and specifically designed storage areas. Extensive use of PCB field test kits aided in the segregation of these soils. The segregation was confirmed through sampling and laboratory analysis before a decision was made on the final management of the excavated soils.

PROJECT MANAGEMENT AND REGULATORY AGENCY COORDINATION

Before the implementation of the excavation activities, a well-defined cleanup approach was developed and presented to NJDEP for approval. Although the approach used state-of-the-art testing technology, the project management approach emphasized close cooperation and coordination among the many project team mem-

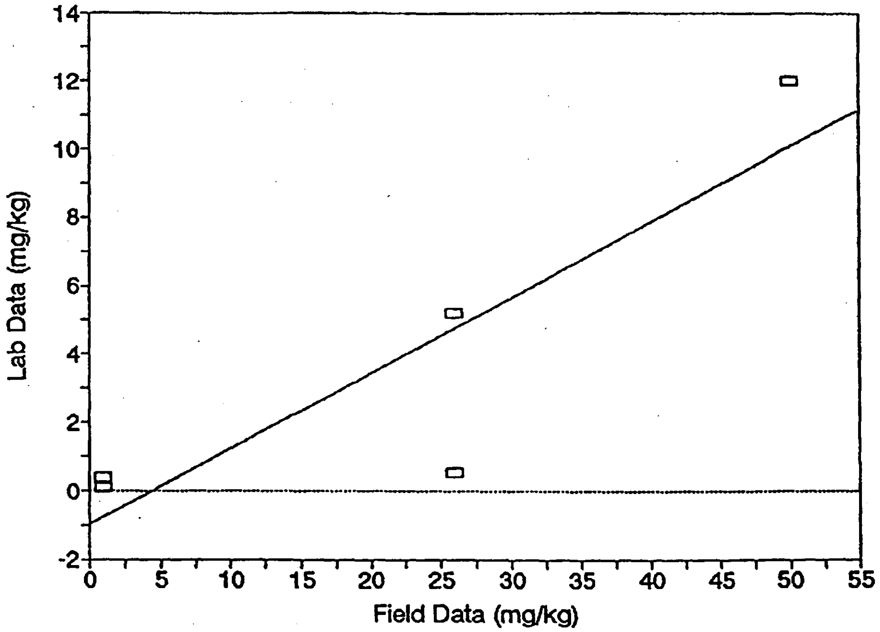

FIGURE 2 Scatter diagram: relationship between PCB data from laboratory analysis and field screening.

TABLE 2 Results of Linear Regression Analysis

Simple Regression	X	1:Field Data (mg/kg) *a*	Y	1:lab Data (mg/kg)

Count:	R:	R-squared:	Adjusted R-squared:	RMS Residual:
6	0.894	0.799	0.749	2.415

Analysis of Variance Table

Source	DF:	Sum Squares:	Mean Square:	F-test:
Regression	1	92.647	92.647	15.89
Residual	4	23.321	5.83	P=.0163
Total	5	115.968		

No Residual Statistics Computed

Beta Coefficient Table

Simple Regression	X	1:Field Data (mg/kg)	Y	1:lab Data (mg/kg)

Variable:	Coefficient:	Std. Err.:	Std. Coeff.:	t-Value:	Probability:
Intercept	-0.912				
Slope	0.22	0.055	0.894	3.986	0.0163

Confidence Intervals Table

Variable:	95% lower:	95% Upper:	90% Lower:	90% Upper:
Mean (X,Y)	0.304	5.779	0.94	5.14
Slope	0.067	0.373	0.102	0.34

a mg/kg = milligrams per kilogram = parts per million

bers, including NJDOT's engineering, environmental, and project support departments; NJDEP; the consultant's own technical staff; and the contractor.

Once the operation started, daily communication with NJDEP was maintained to address the many unknowns that developed during the subsurface cleanup. Although all parties were working with cleanup goals that were well-defined and negotiated before the start of the actual remedial activities, close contact was maintained with the NJDEP case manager during the entire excavation operation to provide a daily status report and solicit feedback and agreement on the future course of action. In addition, close coordination between the consultant, NJDOT's resident engineer, and the contractor resulted in the identification of the most appropriate locations along the right of way where excavated material could be used as fill.

Careful planning of the work and the establishment of an informal but highly effective partnering relationship among all parties resulted in a remedial project that proceeded expeditiously with significant time and cost savings for the client.

CONCLUSIONS

The geophysical surveys provided a noninvasive technique for defining the limits of the buried drums and approximating the amount of waste and potentially impacted soil before the start of excavation. After the excavation was complete, geophysical surveys helped establish that all of the buried drums had been removed.

Field screening by immunoassay testing for PCBs allowed for a rapid and inexpensive way to segregate the soils and minimize the number of postexcavation samples submitted for laboratory analysis. Close liaison with regulatory agencies allowed the project to proceed as planned and maintained the accelerated schedule imposed by construction needs. The site was remediated below the NJDEP proposed cleanup levels. No residual contamination was left on-site, as indicated by the results of the postexcavation sample analyses.

The environmental solution resolved the contamination issue without modifying the construction ramp and highway design. Hence, remediation activities were completed ahead of schedule, which helped to expedite the ramp construction, and the highway was opened to the public as planned.

The actual site remediation cost $3.8 million. The use of immunoassay testing kits, upfront negotiation of cleanup levels, soil segregation, and soil reuse resulted in a $1 million savings from the estimated cleanup cost.

REFERENCE

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