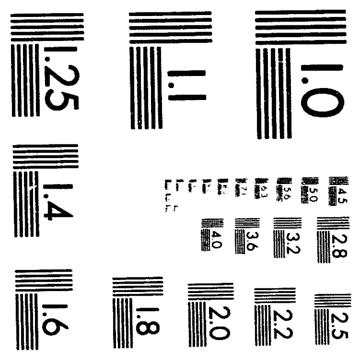
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EXPEDITED SITE CHARACTERIZATION: A RAPID, COST-EFFECTIVE PROCESS FOR PREREMEDIAL SITE CHARACTERIZATION

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ABSTRACT

Argonne National Laboratory has developed a unique, cost- and time-effective, technically innovative process for preremedial site characterization, referred to as Expedited Site Characterization (ESC). The cost of the ESC field sampling process ranges from 1/10 to 1/5 of the cost of traditional site characterization. The time required for this ESC field activity is approximately 1/30 of that for current methods. Argonne's preremedial site investigations based on this approach have been accepted by the appropriate regulatory agencies.

The ESC process is flexible and neither site nor contaminant dependent. The process has been successfully tested and applied in site investigations of multiply contaminated landfills in New Mexico (for the U.S. Department of the Interior's Bureau of Land Management [BLM]) and at former grain storage facilities in Nebraska and Kansas, contaminated with carbon tetrachloride (for the Department of Agriculture's Commodity Credit Corporation [CCC/USDA]). A working demonstration of this process was sponsored by the U.S. Department of Energy (DOE) Office of Technology Development as a model of the methodology needed to accelerate site characterizations at DOE facilities.

Basic features of the ESC process are as follows: (1) A technical manager with a broad base of expertise and a team of scientists with diverse expertise and strong field experience are essential. (2) Participation of the same technical team throughout the processes of planning, field implementation, data integration, and report writing is required. (3) The technical team first *critically* reviews and maximizes use of existing data to form working hypotheses that guide development of the ESC program. (4) The entire technical team visits a site to identify site characteristics that prohibit or promote any hypothesis or technological approach. (5) After the site visit, a suite of noninvasive and minimally invasive technologies is selected, to give greater confidence and overlapping evidence for conclusions about site features. Significant technical advances have been made in the use and integration of surface vegetation sampling, aquifer chemistry and isotopes, deep sampling with an electronic cone penetrometer, sample preservation methodologies, and surface geophysics to delineate and corroborate site details. (6) *In no case is the traditional approach of installing a large number of monitoring wells followed.* (7) A *dynamic* work plan that outlines the program is produced for the sponsoring and regulatory agencies. This plan is viewed as a guide, subject to modification, rather than an absolute, unchangeable document. (8) The manager and the entire team participate in the technical field program, with technical activities occurring simultaneously. (9) Data from the various activities are reduced and interpreted each day by the technical staff. Although computer programs are used to visualize and integrate the data, ***people***, not computers, do the data interpretation and integration. (10) Each day the team and manager meet, review results, and modify the program to optimize activities that are generating overlapping or confirming site details.

The result of this process is the optimization of the field activity to produce a high-quality technical product that is both cost and time effective. Argonne has achieved technically sound site characterizations that are acceptable to regulatory agencies and have provided extensive cost and time savings in both the BLM and CCC/USDA programs.

INTRODUCTION

Governmental agencies are under increasing pressure to remediate hazardous waste sites in a cost-efficient and timely manner. One of the major stumbling blocks in initiating the cleanup process is lengthy and costly site characterization activities that do not produce adequate technical data for proper selection and design of a remedial action. Most often these characterization activities rely on the traditional approach of random grid sampling and/or installation of a massive number of monitoring wells in hopes of generating sufficient data to satisfy a regulatory body. The end result of these activities is most often a constant reiteration of sampling, which leads to cost and time overruns with no definitive conclusions on correct remedial actions.

One of the major goals of the Environmental Research Division of Argonne National Laboratory is to develop and provide governmental agencies with technically sound, cost- and time-effective frameworks for preremedial site characterization. The process developed and proven workable by Argonne for several diverse sites and different agencies is referred to as Expedited Site Characterization (ESC). The ESC process, as presented in this paper and half-day course, is flexible and neither site nor contaminant dependent.

The first portion of this paper and lecture discusses the basic features of the ESC process. The process relies heavily on the use of a scientific approach to problem solving and requires both a technical manager and team members with diverse and considerable scientific capabilities. Both the manager and team members are involved in all phases of the program from planning to field implementation to data reduction and report writing. The ESC emphasizes use of multiple technologies for delineating and corroborating site features rather than random, statistical approaches. Noninvasive or minimally invasive technologies are used rather than the traditional approach of monitoring well installation.

Three examples of the successful implementation of the ESC approach are presented here. The examples are taken from preremedial site characterization studies conducted by Argonne for the Department of Interior, Bureau of Land Management (BLM), in New Mexico, and for the Commodity Credit Corporation, United States Department of Agriculture (CCC/USDA). The BLM program involved design and implementation of the ESC approach for New Mexico landfills thought to contain hazardous waste. The problem faced by the CCC/USDA is soil and groundwater contamination from former CCC grain storage facilities in the Midwest. Specifically, carbon tetrachloride was used to fumigate these grain storage facilities in the 1950s and 1960s. Subsequently, the carbon tetrachloride has leached into the soil and groundwater of several Midwest communities.

The BLM Flora Vista Landfill and the CCC/USDA Waverly, Nebraska, site will be discussed to illustrate the importance of maximizing use of existing data and multiple technologies to provide technically sound data and expedite the preremedial site characterization process. The CCC/USDA Murdock, Nebraska, site investigation illustrates the technical, cost, and time benefits of the ESC's minimally invasive technologies for sampling versus random installation of monitoring wells.

The ESC investigations at all of these sites have been successful in producing high-quality studies that are acceptable to regulators, with significant cost and time savings to the government agencies.

THE ESC PROCESS

The ESC process emphasizes the use of the scientific method to solve site investigation problems with technically defensible data. The basic features and steps of the ESC process are discussed below and outlined in Figure 1.

An experienced technical manager with a broad base of expertise and a team of scientists with diverse expertise and strong field experience are required to make the process work. The Argonne team is composed of geologists, geochemists, geophysicists, hydrogeologists, chemists, biologists, computer scientists, health and safety personnel, and regulatory staff, as well as technical support staff. Of the geoscience staff, seven scientists are at the Ph.D. level, two are at the master's level, and one is at the bachelor level. They have a combined total of 170 years of experience in various aspects of the geosciences. Other disciplines within the team follow approximately the same distribution in terms of degree level and experience. The technical team works together throughout the process. In other words, the team that plans the program also implements the program in the field and writes the reports. Individuals with lesser degrees or experience do not carry out the field work while the more experienced scientist remains in the office.

The technical team first *critically* reviews and interprets existing data for the site and contaminants to determine which data sets are technically valid and can be used in initially designing the field program. One of the most basic mistakes in the site characterization process is failure to use technically sound available data to form working hypotheses on hydrogeology, contaminant distribution, etc. for initial testing.

After assembling and interpreting existing data for the site, the entire technical team visits the site to identify as a group the site characteristics that may prohibit or enhance any particular technological approach. Logistic and community constraints are also identified at this point.

After the field visit, the team selects a suite of technologies appropriate to the problem and completes the design of the field program. No one technique works well at all sites, and a suite of techniques is necessary to fully

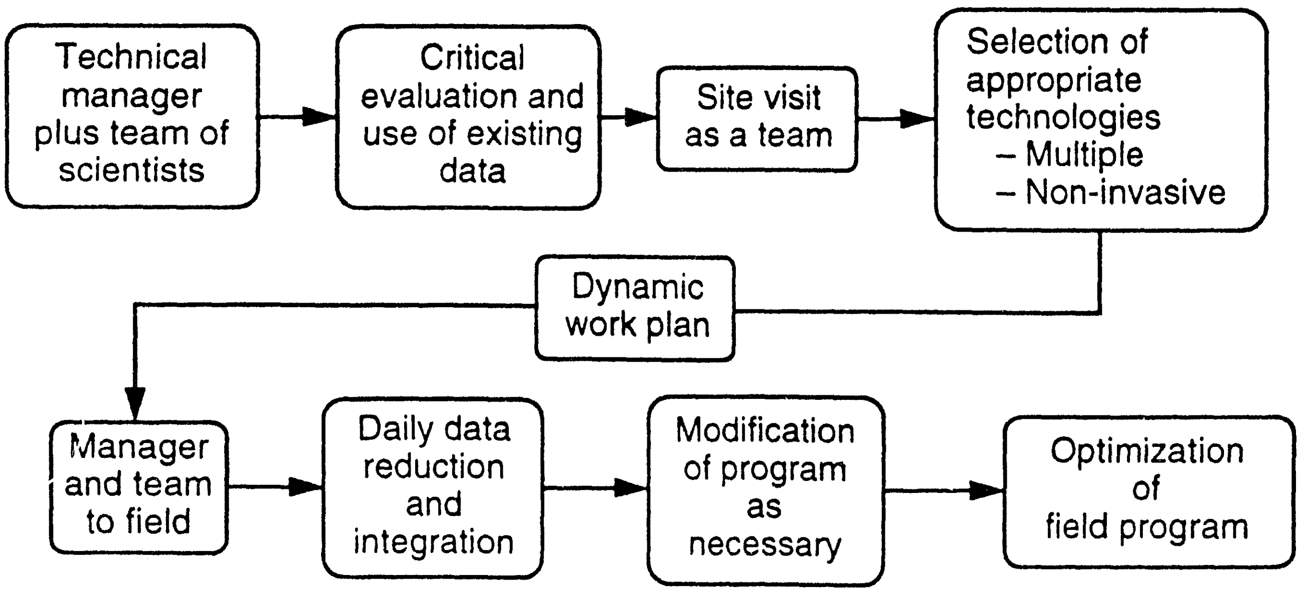

Figure 1. Process for Implementing Expedited Site Characterization

delineate site features. In addition, multiple technologies are employed to give greater confidence in conclusions about site features. Noninvasive and minimally invasive technologies are emphasized to minimize risk to the environment, the community, and the staff. In no case is the traditional approach of installation of a massive number of monitoring wells followed.

A *dynamic* work plan that outlines the program is produced for the sponsoring and regulatory agencies. The word dynamic is emphasized because the work plan is viewed as a guide, subject to modification, for the site characterization activity rather than a document that is absolute and unchangeable. Therefore, the health and safety plan and quality assurance/quality control plan must be broad and encompass all possible alterations to the work plan. The cooperation of the regulating agency is essential in successful implementation of this process.

The entire team participates in the technical field program. Several technical activities are undertaken simultaneously. These may range from different surface geophysics investigations to vegetation sampling. Data from the various activities are reduced and interpreted each day by the technical staff. Various computer programs are used to visualize and integrate the data. However, *people* do the data interpretation and integration, not computers. The computers are just one more tool in use at the site.

At the end of the day, the staff members meet, review results, and modify the next day's program as necessary to optimize activities that are generating overlapping or confirming site details. Data are not arbitrarily discarded — each finding must be explained and understood. Anomalous readings may be due to equipment malfunctions, laboratory error, and/or the inability of a technique to work in a given setting even though theoretically it should.

The end result of this process is the optimization of the field activity to produce a high-quality technical product that is cost and time effective.

EXAMPLES OF ESC PROCESS IMPLEMENTATION

Three examples of the successful implementation of the ESC methodology are discussed below. The BLM Flora Vista Landfill program in New Mexico is an example of the use of noninvasive, multiple geophysical technologies to delineate important site features for site characterization and to determine whether remediation is needed. The CCC/USDA Waverly, Nebraska, site illustrates the importance of critically evaluating existing data in forming working hypotheses for site characterization. In addition, the Waverly program demonstrates the benefits of multiple technologies in the ESC methodology in interpreting site hydrogeology and contaminant movement. The third example, the CCC/USDA Murdock, Nebraska, site, illustrates the technical, cost, and time benefits gained by the ESC process in its emphasis on minimally invasive sampling methodologies rather than monitoring well installation for groundwater and soil sampling during the characterization process.

Flora Vista Landfill

Geologic Setting and Site History

The BLM's Flora Vista Landfill is an inactive landfill located approximately 5 mi west of Aztec and approximately 6 mi northeast of Farmington in San Juan County, New Mexico (Figure 2). The landfill covers 13 acres and is a

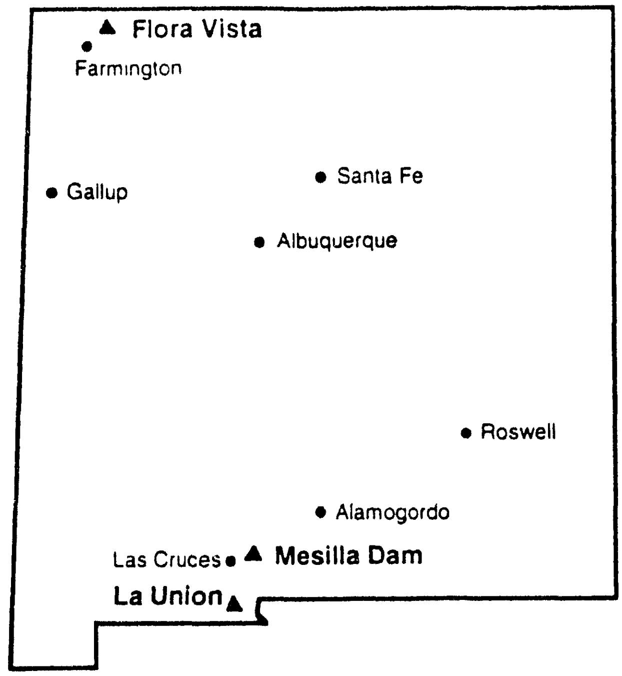

Figure 2. Location of Flora Vista Landfill in New Mexico

modified sanitary (not covered daily) landfill that was leased and used by San Juan County from July 1978 through 1989. The State of New Mexico Environmental Improvement Division alleged in 1986 that large quantities of petroleum, industrial, or other hazardous waste had been deposited at the Flora Vista Landfill between the 1970s and August 1985. These wastes were supposedly deposited in septage waste pits at the site without the BLM's authorization. Written disposal records were not maintained by the county or BLM during the life of the landfill. Therefore, allegations of hazardous waste disposal could not be confirmed or denied on the basis of any written records.

The BLM authorized both a preliminary assessment (PA) in 1986 (AEPCO, Inc., 1986) and a site investigation (SI) in 1987 by a private contractor (Roy F. Weston, 1988). Both contractors generated maps of previously covered trenches and pits. However, these maps yielded conflicting results that Argonne could not readily explain because of the paucity of written records for the landfill. Surface and subsurface soil samples were collected during the PA and SI programs. Analytical results from both the PA and SI samples indicated the presence of some hazardous compounds (tetrachloroethylene, toluene, benzene, acetone, 4-methylphenol, 1,1,1-trichloroethane, etc.) in one septage pit area of the landfill. In addition, the SI results were interpreted by the contractor as indicating possible lateral and vertical migration from this pit. Recommendations of the SI included the drilling of five monitoring wells at the site. On the basis of the results of the PA and SI, operation of the landfill was suspended, and the landfill was covered with approximately 2 ft of sandy soil. Argonne was then asked to initiate an expedited preremedial SI to determine if remediation of the landfill was required.

ESC Program for Flora Vista

The ESC was designed as a two-phase program. The first phase consisted of geological and geophysical investigations to identify source areas (previously unmapped trench and pit areas; contaminant plumes) and migration pathways (in the subsurface, bedrock and groundwater levels and aquitards; on the surface, arroyos and topographic relief). This information was then used to select sampling locations for the second phase of the program, testing for migration from source areas. If necessary, a third phase incorporating data from the first two phases would be initiated to locate monitoring wells.

Only the results of the first phase of the program for Flora Vista are presented here. All available geological and site history data were used for reconstructions, and four surface geophysical investigations were conducted. The features targeted for location by the four techniques were the following: for seismic refraction, subsurface lithologies and the water table; for electromagnetics (frequency and time domain), buried trench and pit boundaries, conductive plumes, subsurface lithologic features, and the water table; for magnetics, buried trenches; and for resistivity, lithologic characteristics and the water table.

The existing data on the disposal history of the Flora Vista Landfill were extremely sparse at the beginning of the Argonne program, as discussed above. Before the site visit by Argonne staff, the landfill had been covered with 2 ft of sandy soil, fenced, and closed. In addition to the exterior fence, the county had fenced one interior area in the southwest corner of the landfill, where a septage pit was supposedly located. Except for this area, no records indicated the locations of additional pits or trenches (the principal source areas for contaminants at the landfill). Therefore, the initial program was designed with two major objectives: (1) mapping now-buried source areas (trenches and pits) and (2) defining migration pathways for contaminant movement from these source areas (bedrock surfaces, clay lenses, surface drainage patterns, etc.). When the source and migration routes were delineated, an optimal sampling program could be designed to fully test migration from these sources.

Source Areas. The geophysical techniques for mapping trenches and pits included magnetometer and electromagnetic (EM) surveys. The EM31 and EM34 surveys were used for mapping pits because one of the chief fears was that oil field wastes might have been placed in the landfill trenches and pits. These materials are frequently conductive and should be detected by the EM equipment. The chief emphasis was on the EM31 for pit and trench mapping because of the shallow depth and because no shallow clay layers had previously been observed in the immediate vicinity of the landfill. The depth of exploration for the EM34 (about 50 ft) is much deeper than for the EM31 (about 15 ft). Regional geologic data indicated that clays could lie at this depth (30-50 ft). Therefore, the EM34 measurements might indicate clay units rather than conductive fluids associated with landfilling activities. For our purposes, however, in the early stages of this program, we included anomalies from the EM34 data in the trench mapping because we felt that in either case, clay versus fluid, we would want to test that particular area.

The results of the magnetometer, EM31, and EM34 surveys (Figures 3-5, respectively) show that several areas repeatedly appeared as anomalies with the different techniques. However, some areas yielded a response to only one technique, such as the fenced area in Figure 4 for the EM31 survey. This location is of particular interest because it is the supposed septage pit area fenced by the county just before the landfill was closed. The fact that this area was responsive to the EM31 and not the magnetometer or EM34 indicates that it may well be a near-surface pit containing conductive materials. One feature to note is that the boundaries of the anomaly appear to extend well beyond the county's fence line.

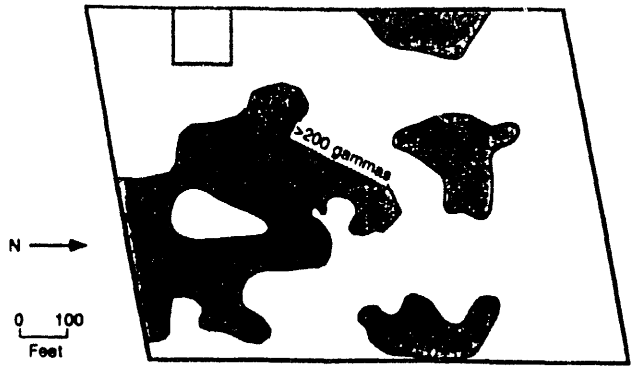

Figure 3. Geophysical Magnetic Survey Identified Portions of Some Solid Waste Trenches

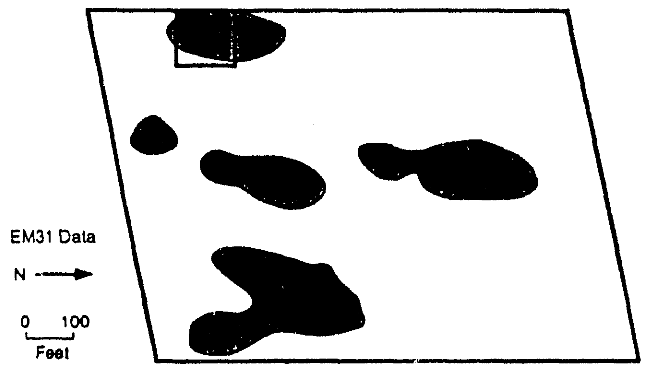

Figure 4. Anomalous Values from EM31 Survey Located Conductive Fluids and Solids at the Landfill

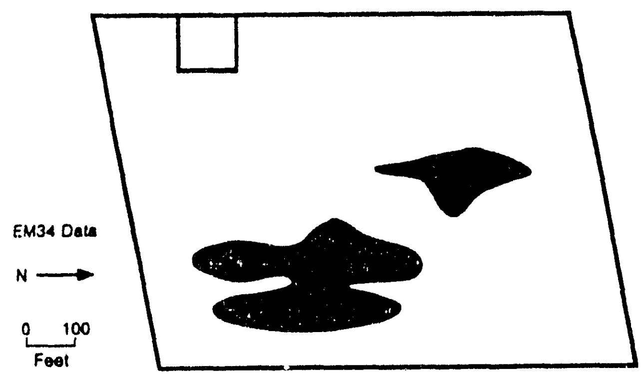

Figure 5. Anomalous Results of EM34 Survey Indicative of Solid Waste Trenches at the Flora Vista Landfill

The anomalous areas identified by each survey were next overlain to generate a map of potential source areas (both pits and trenches) for the landfill (Figure 6). This process will be described after the migration pathways have been identified in the next section.

Migration Pathways. The next step in the program was to determine if any technique was generating data that would be useful in delineating information on migration pathways. After two days in the field, it was evident that the seismic refraction survey was mapping a bedrock surface at fairly shallow levels (15-45 ft) beneath the landfill surface. This relatively shallow bedrock surface had not been predicted by the regional geologic data (Baltz et al., 1966; Stone et al., 1983; Welder et al., 1986). However, inspection of several

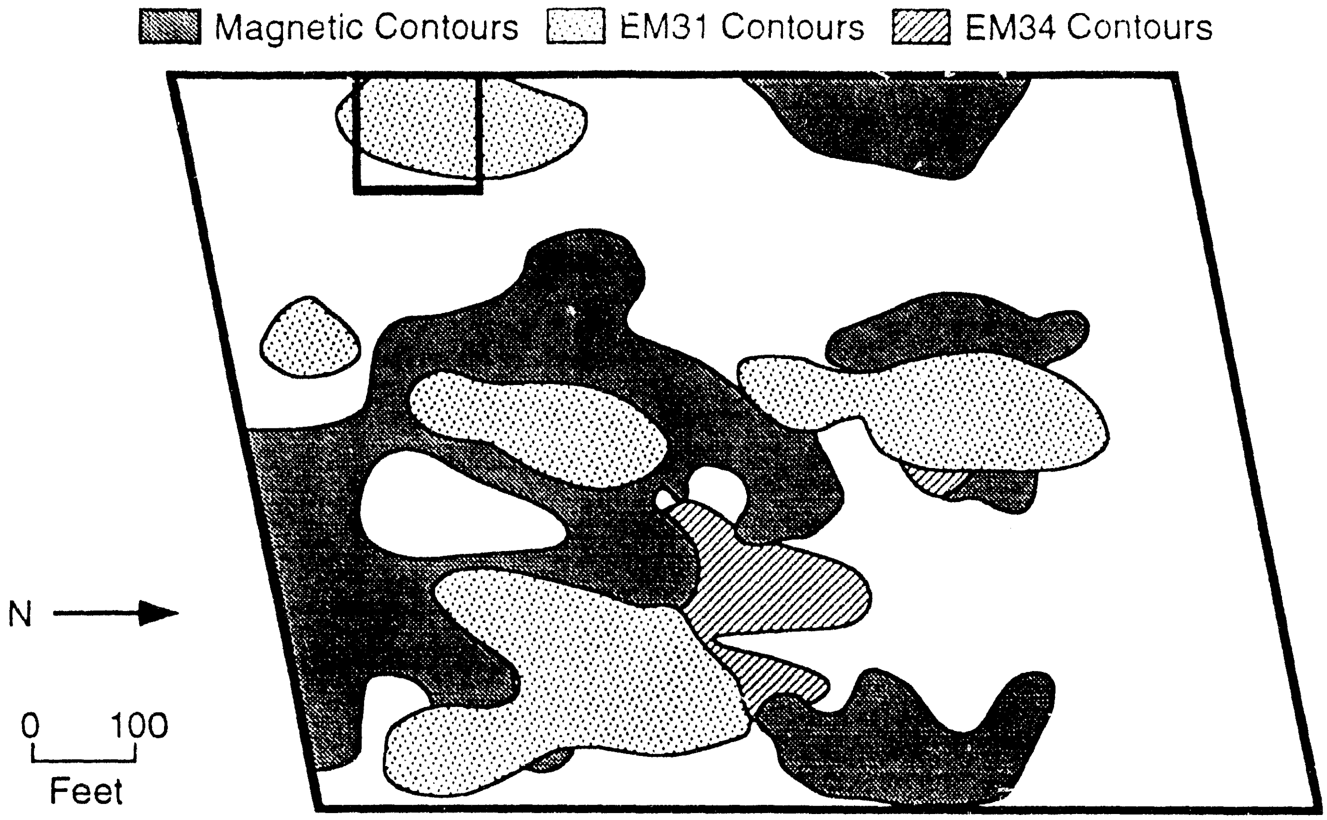

Figure 6. Magnetic and Electromagnetic Data Were Combined to Establish Probable Locations of Shallow and Deep Waste Materials

nearby outcrops indicated that the Tertiary Nacimiento Formation could be present as an erosional bedrock surface at the landfill site. The Nacimiento is a hard, lithified, fairly impermeable sandstone. Because it was believed that this surface might play an important role in unsaturated flow from the trenches and pits, the field program was altered to include a more comprehensive seismic refraction survey within and immediately around the landfill. Thirty-eight profiles with short spreads of 130 ft were acquired inside the fence (Figure 7). These data provided 76 depths to bedrock beneath shot points that were used to construct a bedrock topography map (Figure 7).

As Figure 7 shows, the bedrock surface is an erosional surface with valleys, depressions, and definite drainage patterns. In addition to defining potential subsurface flow directions, a topographic map was constructed in the field for the landfill itself (Figure 8). This surface map was then used to define surface migration pathways from the landfill.

Integration of Data and Selection of Sampling Sites. The data on source areas and potential migration pathways were combined to prioritize sample locations for the site (Figure 9). Source areas were represented by integrating the magnetic, EM31, and EM34 contours taken from Figures 3-5. Principal subsurface migration pathways were represented by the thin lines from the bedrock mapping (Figure 7) and principal surface migration pathways by the thick lines from the surface topographic mapping (Figure 8). Sampling and soil boring locations could now be chosen to test for movement or leaching of materials from these source areas without drilling into a trench or pit in the first phase of the program. This restriction eliminated the possibility of introducing contamination into the subsurface by arbitrary drilling through potentially contaminated pits and trenches. Inspection of the sampling and soil boring locations in Figure 9 reveals that all major migration pathways were tested.

Results of Field Testing of Source and Migration Pathway Predictions

When soil borings were installed, the trench areas trending north-south in the landfill were found to be real. The accuracy of predictions of trench boundaries was within 5 ft. Predicted depths to bedrock were accurate within 10 ft, and the soil borings substantiated the general nature of the bedrock surface.

The only pit area actually drilled was the fenced area mapped by EM31 (Figure 9). During the SI, the contractor had drilled two soil borings in this pit area, one inside the fenced area and one just south of the southern interior fence boundary. On the basis of the analytical results from this drilling, the contractor had proposed that lateral and vertical migration of contaminants had occurred from the pit area. The location of the contractor's two soil borings (WB1 and WB2) are shown in cross-sectional view in Figure 10 with Argonne's soil borings in this pit area, with the results of the EM31 study superimposed. Argonne's soil borings, coupled with a reexamination of the contractor data and the EM31 response, proved that this is actually one large septage pit and that no lateral or vertical migration has occurred from it. The interior fence is just an artificial boundary that is not at all representative of the extent of the pit. Without the EM31 data, outlining the possible boundaries of the pit, and the seismic data, giving an idea of the location of the base of the pit, considerable time and money could have been wasted in drilling and attempting to understand this one area.

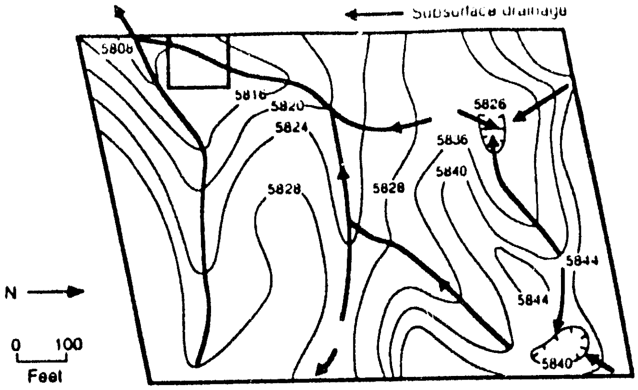

Figure 7. Seismic Refraction Survey Identified a Consolidated Bedrock Surface beneath the Landfill that Controls Subsurface Flow

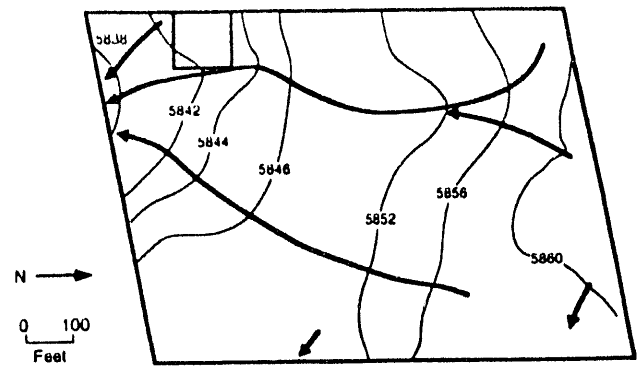

Figure 8. Surface Topographic Map Shows Direction of Surface Drainage at the Landfill

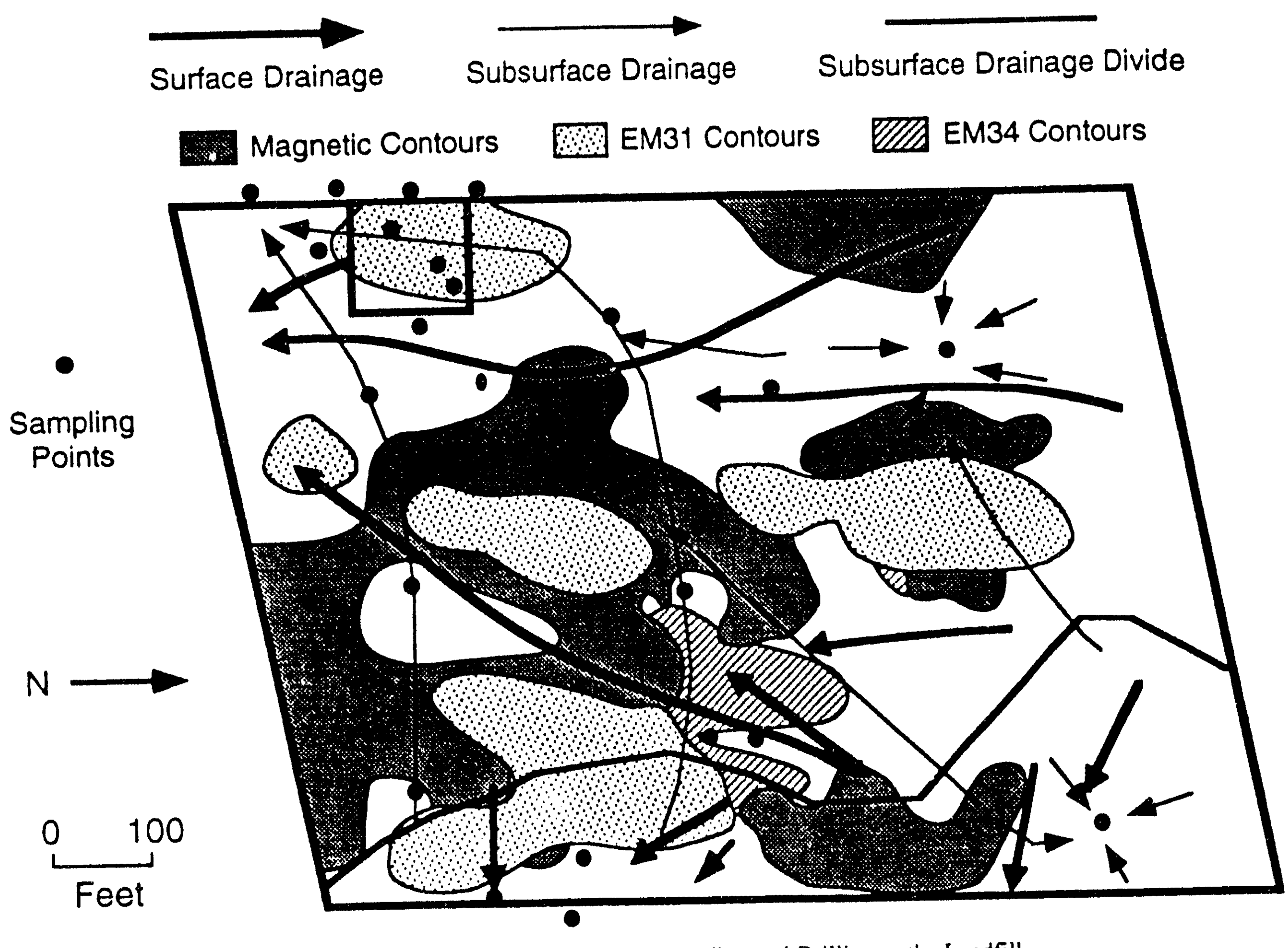

Figure 9. Integration of All Data Established a Framework for Sampling and Drilling at the Landfill

Hydrogeology and Depth to Water Table

Surface geophysical programs were also integrated with geological data to define the depth to the water table at Flora Vista and the nature of the geologic units from the surface through the water table. Significant results of that portion of the program are as follows: (1) Seismic refraction, resistivity, and time-domain electromagnetic (TDEM) studies all predicted that the water table was 150 ft beneath the surface. These predictions were confirmed when two existing wells were located near the site and the depth to water was measured at 150 ft. (2) Seismic refraction predicted that consolidated bedrock extended from 40 ft beneath the surface through the water table interface. (3) TDEM and frequency-domain electromagnetic studies identified clay layers (aquitards) in the subsurface. (4) The existence of both the clay layers and the bedrock was confirmed by drilling.

Discussion

Results from the ESC program demonstrated that groundwater is not threatened by the migration of materials from the Flora Vista Landfill. Only low levels of volatile and semivolatile organic compounds and metals (e.g., acetone,

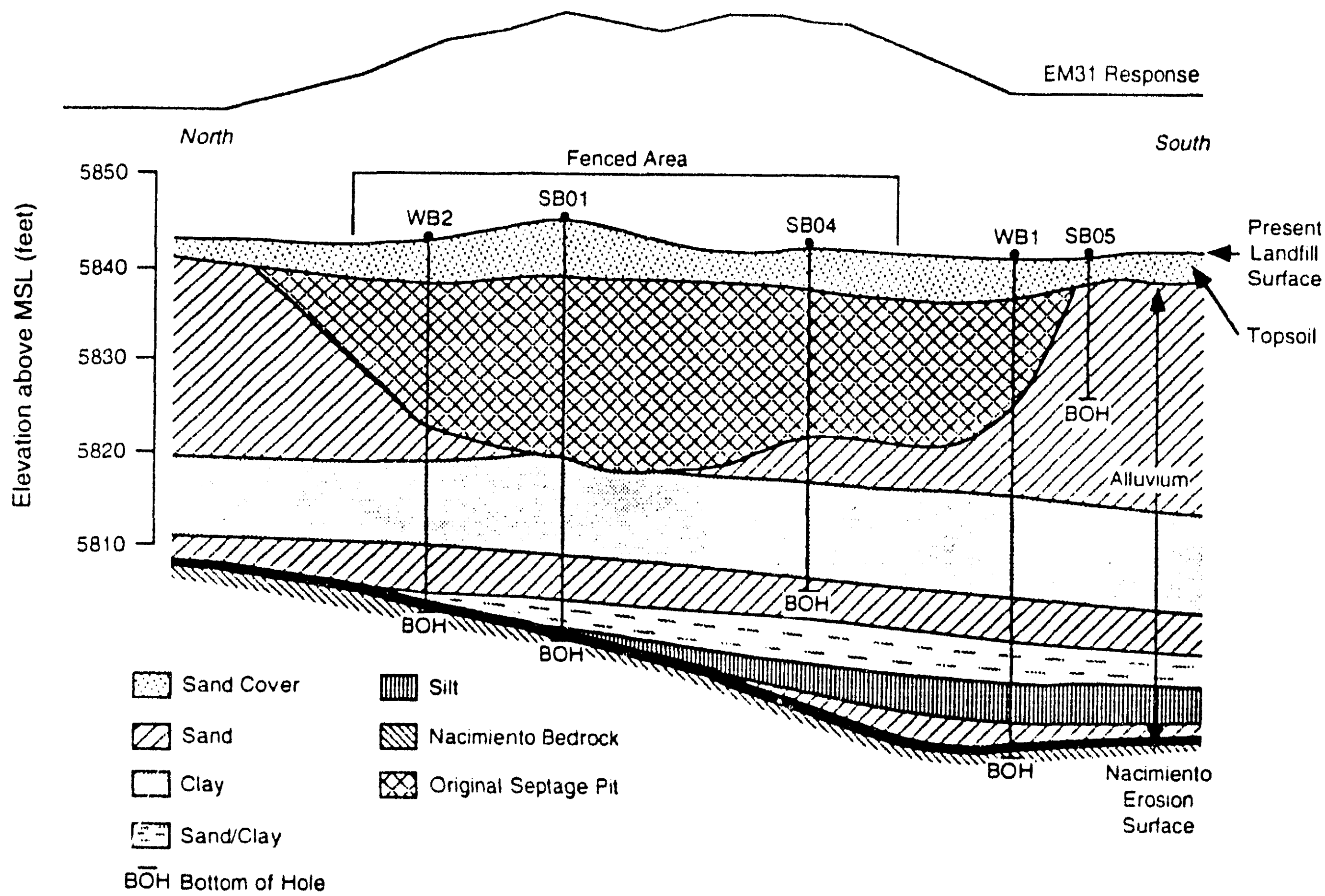

Figure 10. Drilling Confirmed the Position of the Waste Pit Predicted by the Electromagnetic Survey

benzene, chlorobenzene, ethylbenzene, naphthalene, toluene, xylene, lead, chromium, and zinc) were found in isolated locations in the septage pit of the landfill and nowhere else on the site. No evidence exists for either lateral or vertical movement these contaminants from the waste pit or landfill. Future movement is unlikely because the area receives < 8 in. of rainfall annually.

Groundwater occurs at depth of approximately 150 ft beneath the landfill. The groundwater is protected from migration of potential contaminants by 85-100 ft of Nacimiento consolidated bedrock and 10-20 ft of clay in the alluvium.

Argonne recommended closure of the landfill with no installation of monitoring wells or remediation required by the BLM. These recommendations were accepted by the appropriate regulatory agencies.

Waverly, Nebraska, Site

Site Setting and History

At the CCC/USDA Waverly site in southeastern Nebraska, carbon tetrachloride was found in a public supply well (1,100 ppb and 710 ppb) in 1986. Site investigations in 1987 by the Region VII U.S.

Environmental Protection Agency (EPA) established that carbon tetrachloride soil contamination at the former CCC/USDA grain storage facility was responsible for the groundwater contamination (Woodward-Clyde, 1988). Site characterization studies conducted by a private contractor concluded that the groundwater regime at the Waverly site consisted of a single aquifer in a sand unit with an intermittent clay layer. Groundwater flow was estimated to be toward the north-northwest (Figure 11). The contaminated public and domestic wells were located northeast of the former CCC/USDA site. Pumpage from the public well was thought to be responsible for drawing the contamination to the northeast.

On the basis of this site characterization study (Woodward-Clyde, 1988), a groundwater extraction well (GWEX) and a vapor extraction system (VES) were installed by the EPA at Waverly as part of an emergency removal action in 1987-1988. In 1988, operation of the GWEX and the VES system was turned over to the CCC/USDA. The remedial systems have significantly decreased the carbon tetrachloride concentrations in the soil vapor and groundwater at the former CCC/USDA site. In addition, groundwater contamination in a public supply well and monitoring wells located on and northeast of the site has fallen below detectable levels. However, a domestic well located farther northeast of the site and estimated to be within the capture zone of the GWEX continued to show carbon tetrachloride contamination (Figure 11). Because the groundwater flow direction was thought to be to the northwest from the site, continued contamination in the domestic well was difficult to understand, especially because contaminant levels in monitoring wells located between this domestic well and the site had fallen below the detection limit.

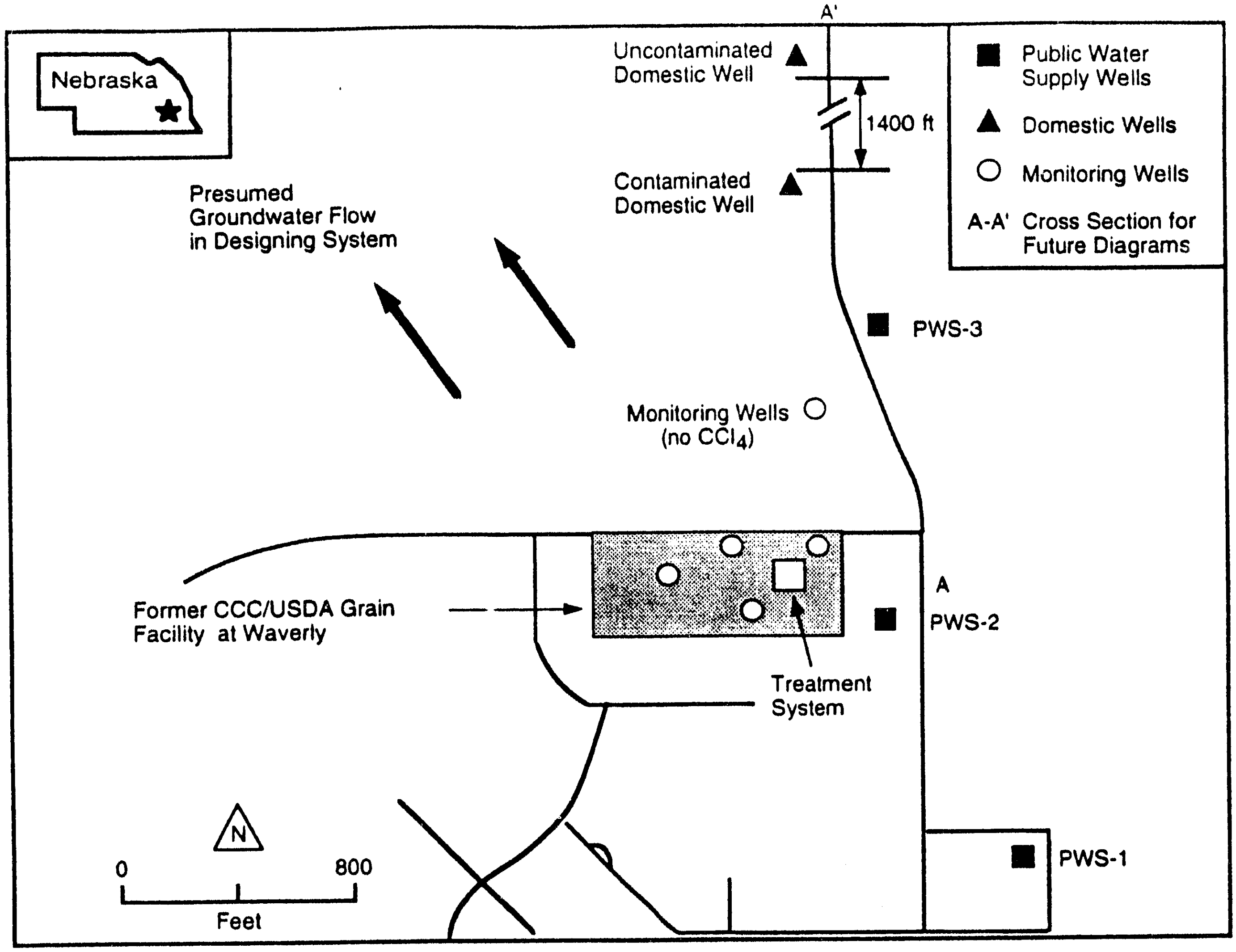

Figure 11. Waverly, Nebraska, Site, with Direction of Groundwater Flow Presumed from Previous Investigations

A Record of Decision (ROD) for Waverly was issued by the EPA in 1990. Among other items, the ROD required an explanation of the contamination in the domestic well northeast of the site and reevaluation of the area of influence of the existing GWEX. At this point, the CCC/USDA requested Argonne's assistance in addressing these two issues.

The ESC Process

Evaluation of Existing Data. The first step in the ESC process for Waverly was critical review and evaluation of existing data. Although the private contractor performing the initial SI had compiled all existing well data, no effort had been made to use these data to understand the geology and hydrogeology of the site (Woodward-Clyde, 1988). A review of the available geologic logs of monitoring wells, irrigation wells, and public supply wells, coupled with geologic reconstructions based on these well data, indicated that two sand aquifer units separated by a continuous clay layer were present immediately beneath the Waverly site (Figure 12). This concept is directly opposed to the conclusions reached in the previous SI, in which one aquifer was postulated for the Waverly site. In addition, evaluation of major ion chemistry in groundwater samples from monitoring wells installed at the site indicated significant differences between the upper and lower sand units (Figure 13).

Use of these existing data led to the conclusion that the groundwater flow direction for the upper aquifer was most likely to the north-northeast and not the north-northwest (Figure 14). The mistake in determining the flow direction occurred because the previous contractor assumed that one aquifer was present and mixed water level measurements from the upper and lower aquifers. (Only the upper aquifer is contaminated at the Waverly site.)

To substantiate the northeasterly flow direction of the upper aquifer, groundwater levels were recorded before the field investigations began by using monitoring wells installed in the upper and lower aquifers during the previous site characterization efforts at Waverly. These measurements indicated that the groundwater flow in the upper aquifer was to the northeast, not to the northwest as determined in the previous study (Figure 14). The water level elevation in the lower aquifer was about 1 ft lower than that in the upper aquifer. Nevertheless, water levels in the lower aquifer were not influenced by pumpage in the upper aquifer, indicating a lack of hydraulic connection between the two aquifers.

However, as Figure 12 shows, the behavior of the aquifer systems about 3,000 ft north of the former grain storage facility could not be stated with any degree of certainty

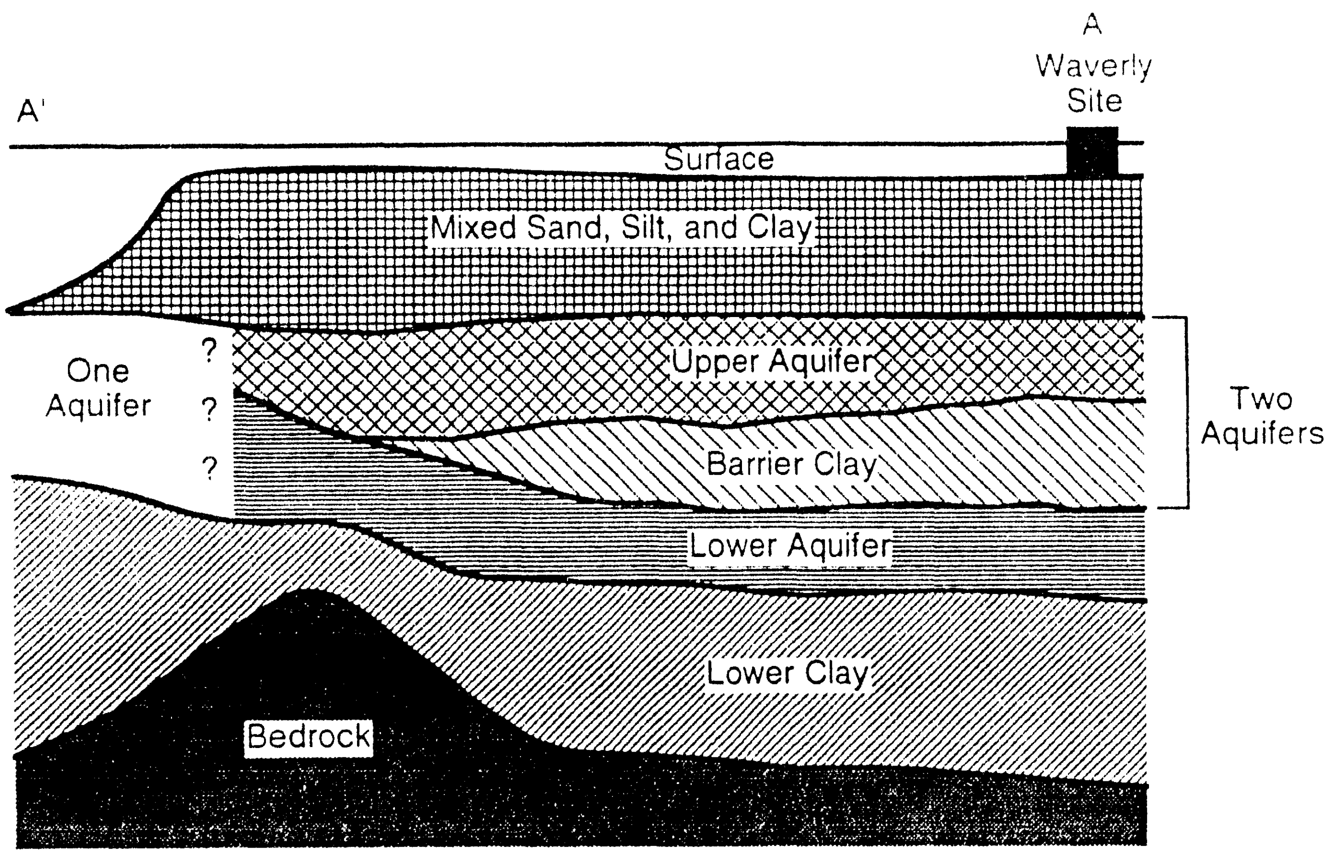

Figure 12. Revised Concept of Aquifer System at Waverly, Produced by ANL with a Review of Existing Data

(line A-A', Figures 11 and 14). Well logs in this area indicated a one-aquifer system. Whether the two aquifers beneath the former grain storage site merged or one was pinched out was unknown.

The ESC field program was designed to answer specific questions in light of this new model for the aquifer systems. The major objectives were (1) to verify the presence of two aquifers north of the site and determine if they merge or if one aquifer is pinched out and (2) to determine the extent of any previously unmapped contamination in the upper aquifer.

As a reference point for the field studies, a type geologic section with data from immediately beneath the former grain storage site was established for comparison with and interpretation of field data from north-northeast of the site (Figure 15). Geologic data along line A-A' (Figure 14) were gathered from soil borings (made with a hollow-stem auger or a mud-rotary drill). Groundwater samples were obtained with a HydroPunch for analysis of major ions, isotopes, and carbon tetrachloride, for comparison with known aquifer chemistries immediately beneath the former CCC/USDA site. A surface time-domain geophysics investigation was conducted along line A-A' in an attempt to help map and substantiate or disprove the continuous nature of the clay layer separating the two aquifers. The use of data from these three different methodologies to reach conclusions on hydrogeologic features at Waverly increased the credibility of the results generated by the ESC process without installing a large number of monitoring wells.

Use of Geology. Six soil borings were drilled to the northwest, north, and northeast of the site to evaluate the continuity of the two sand units and the intervening clay

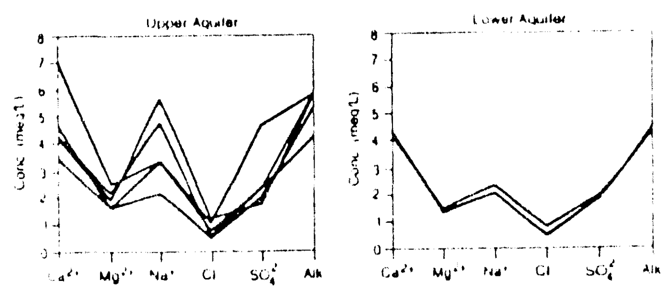

Figure 13. Major Element Chemistry of the Two Aquifers at Waverly

clayer. Geologic logs of the soil borings indicated the presence of clay and sand units away from the site (Figure 16). However, the geologic data could be interpreted to indicate either that both of the sand units and the intervening clay were continuous across the area of investigation or that the upper aquifer was pinched out to the north. Therefore, the geologic data could not be used alone to delineate the exact hydrogeologic relationships north of the site.

Use of Groundwater Geochemistry. Groundwater samples were collected with a HydroPunch from the six soil borings drilled for the geology study along line A-A'. Comparison of the major ion and tritium isotopic compositions of the groundwater samples collected from these soil borings to the reference geochemical data (Figure 17) provided strong evidence that the upper aquifer is absent away from the Waverly site (Figure 18). The ionic tritium concentrations of groundwater samples collected above and below the clay layer intersected in soil borings about 2,000 ft north northeast of

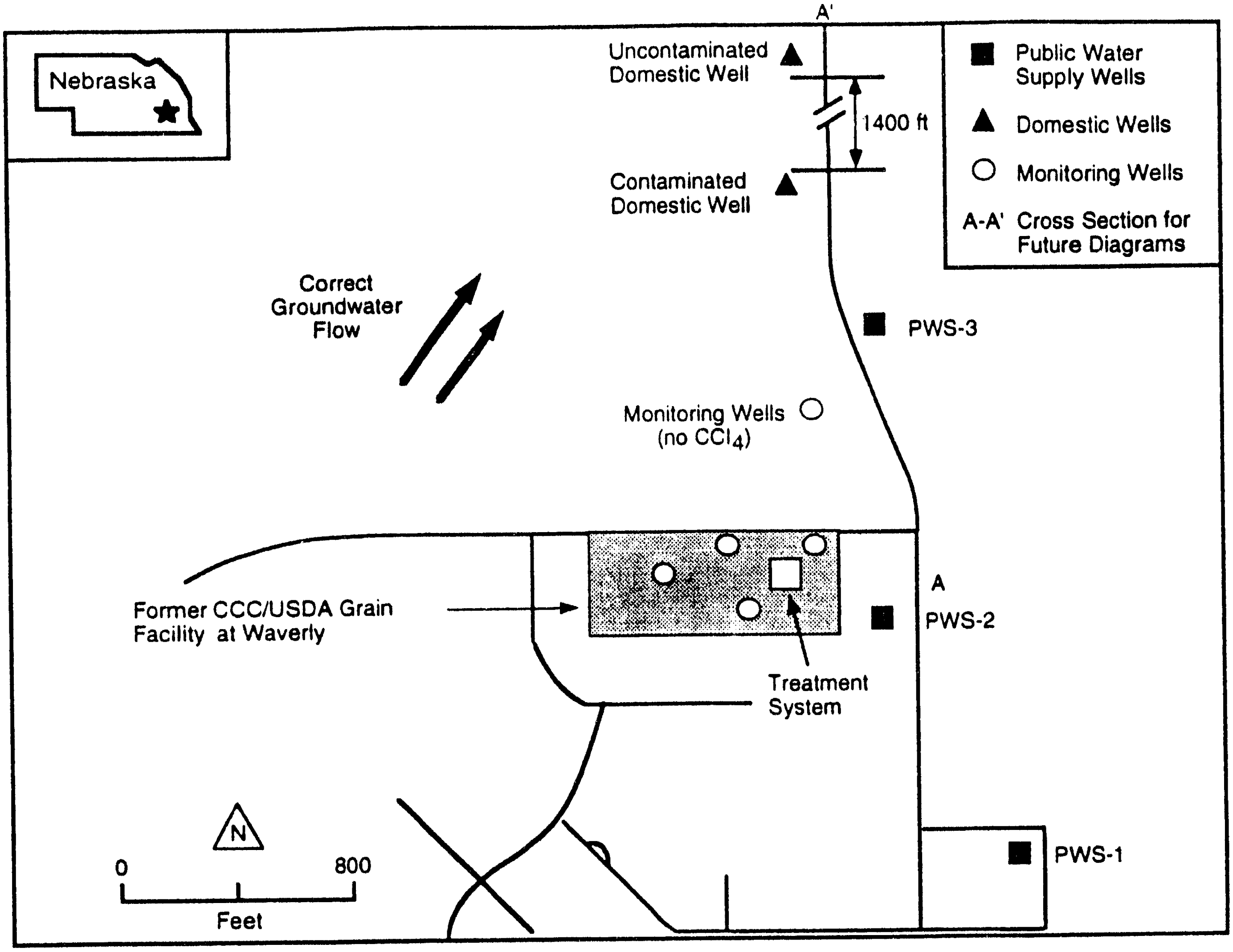

Figure 14. Direction of Groundwater Flow in the Upper Aquifer at Waverly, Determined by ANL from a Review of Existing Data

the site were low and less variable, similar to those of samples from the lower aquifer at the site (Figure 17). This result indicates that the upper aquifer is absent north of the site. The geochemical data further indicate that the hydraulic separation between the two aquifers is maintained away from the site and that contamination is not migrating to the lower aquifer. The geochemical data, therefore, allowed questions left from the geologic interpretation to be answered and the interpretation of the aquifer system to be further refined.

Use of Surface Geophysics. Additional evidence for the absence of the upper aquifer north of the Waverly site was obtained from surface geophysical surveys. A TDEM survey was performed along line A-A' (Figure 14) in the areas of soil boring investigations. Data reduction using traditional techniques produced a subsurface profile (Figure 19) that was inconsistent with the known geologic relationships at the site (Figure 15). Consequently, the data were reprocessed with the more sophisticated technique of image inversion. This technique does not require a priori constraints on the number of lithologic layers, as do the traditional methods; therefore, it provides a more unbiased means of interpreting the geophysical data. Results of the image inversion processing of TDEM data are shown in Figure 20. The disappearance of the upper aquifer sand unit is indicated to the north, consistent with the geochemical data.

Use of an Integrated Model. Figure 21 shows the integrated model of the geologic and hydrogeologic relationships at Waverly, based on the geological, geochemical, and geophysical data. As this diagram shows, the upper aquifer is pinched out the north-northeast of the site, and only the lower aquifer is present. No merging of the two aquifers occurs.

On the basis of this hydrogeologic model, carbon tetrachloride values obtained from the HydroPunch sampling, and the history of contamination and pumpage from adjoining wells, the configuration of the contaminant plume was reconstructed. This reconstruction indicated that the capture zone of the GWEX installed at Waverly was insufficient to capture the entire plume. The portion of the plume captured by the GWEX continued to migrate to the north st, along the natural direction of groundwater flow. This portion of the plume is the cause of the continued contamination in the domestic well northeast of the Waverly site. The predicted plume configuration was confirmed by additional drilling and groundwater sampling (Figure 22).

Discussion

At the CCC/USDA Waverly site, improper use of existing data prevented full understanding of the hydrogeologic system before remedial construction began. The end result was

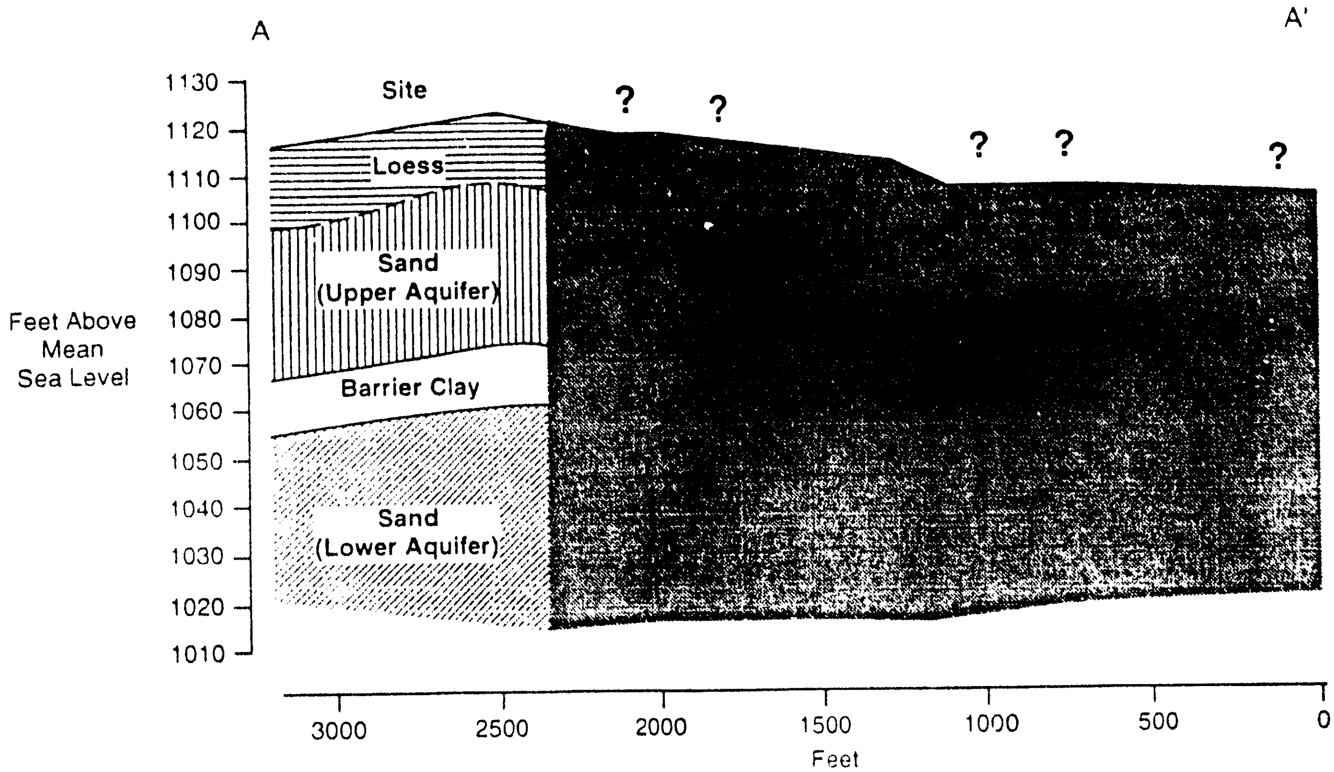

Figure 15. Type Geologic Section Directly Beneath Former CCC/USDA Site at Waverly

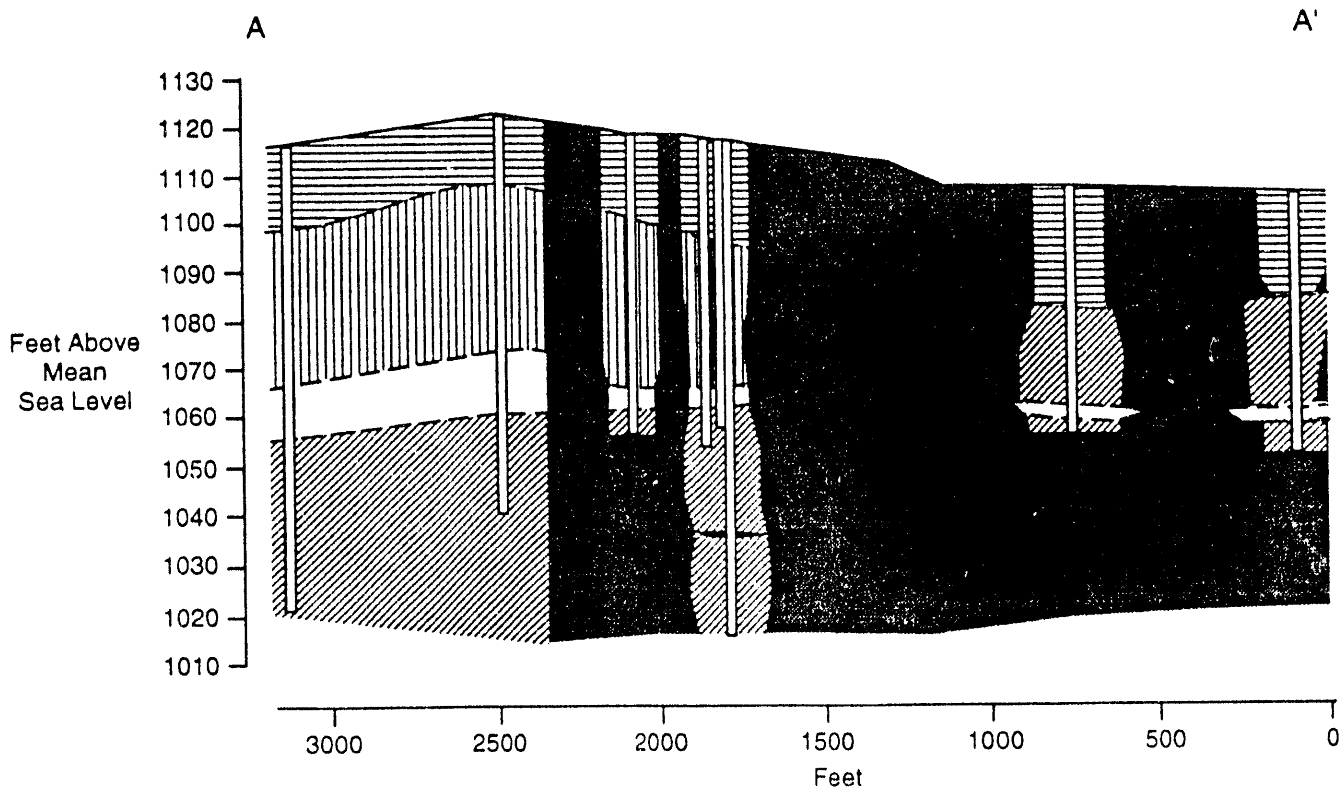

Figure 16. Geologic Log Data at Waverly Allowed More than One Possible Interpretation for Aquifer Sand Units

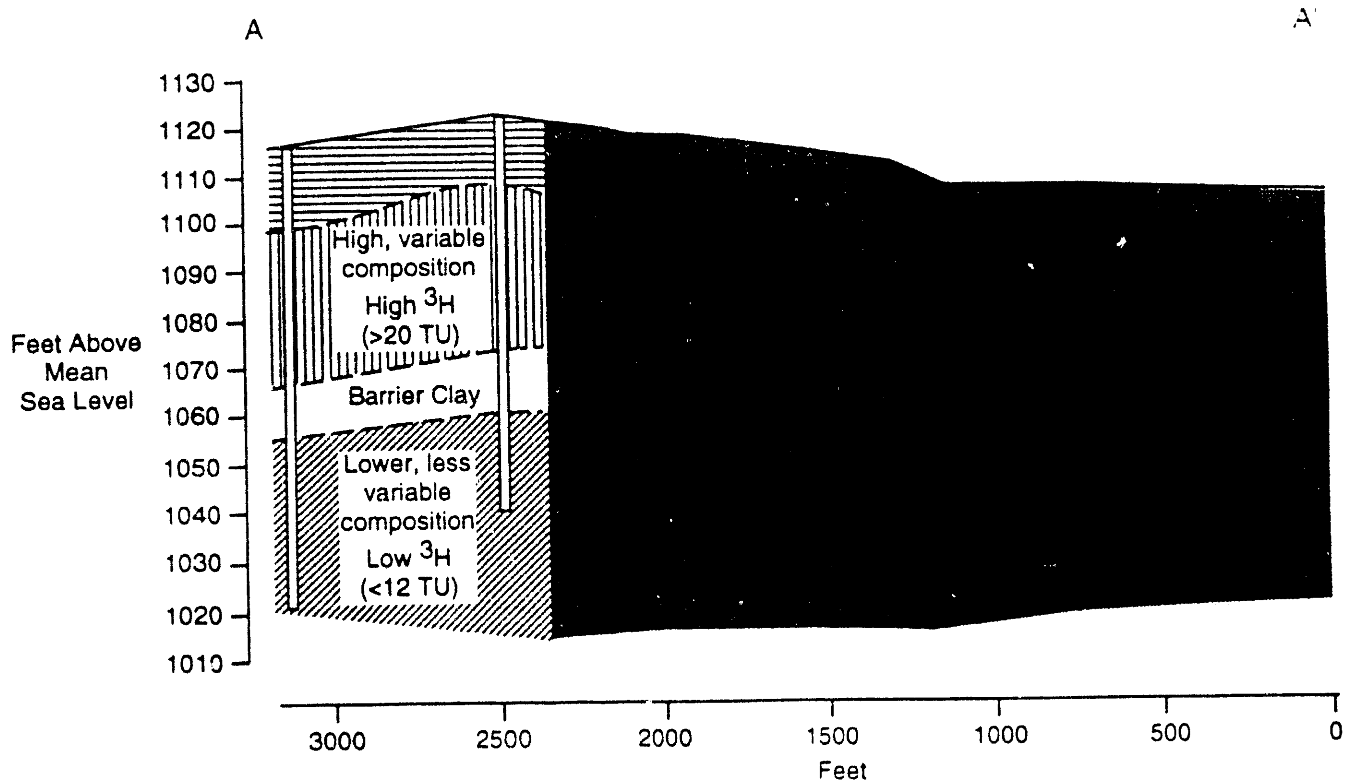

Figure 17. Geochemical Data for the Waverly Aquifers Directly Beneath the Former CCC/USDA Site

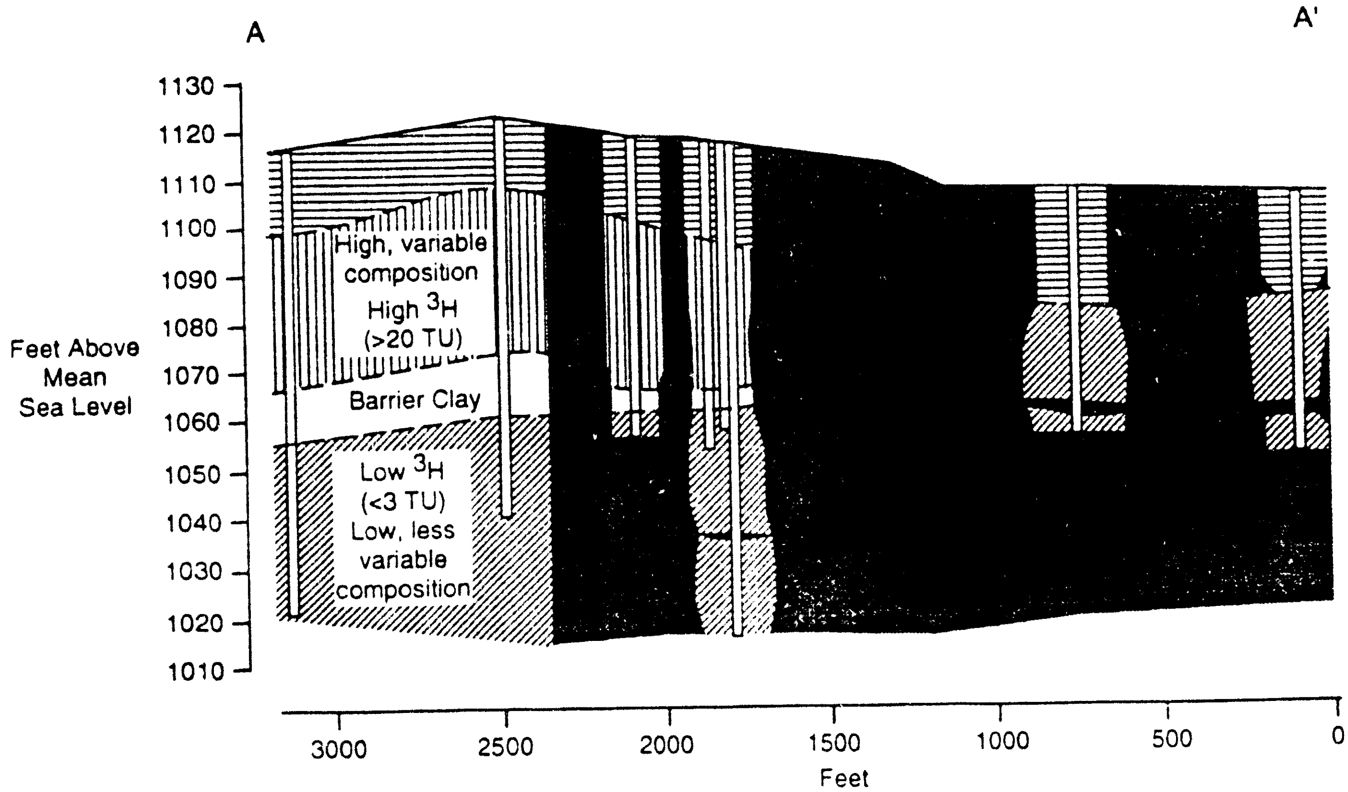

Figure 18. Geochemical Data Were Crucial in Correctly Defining the Hydrogeological Regime at Waverly

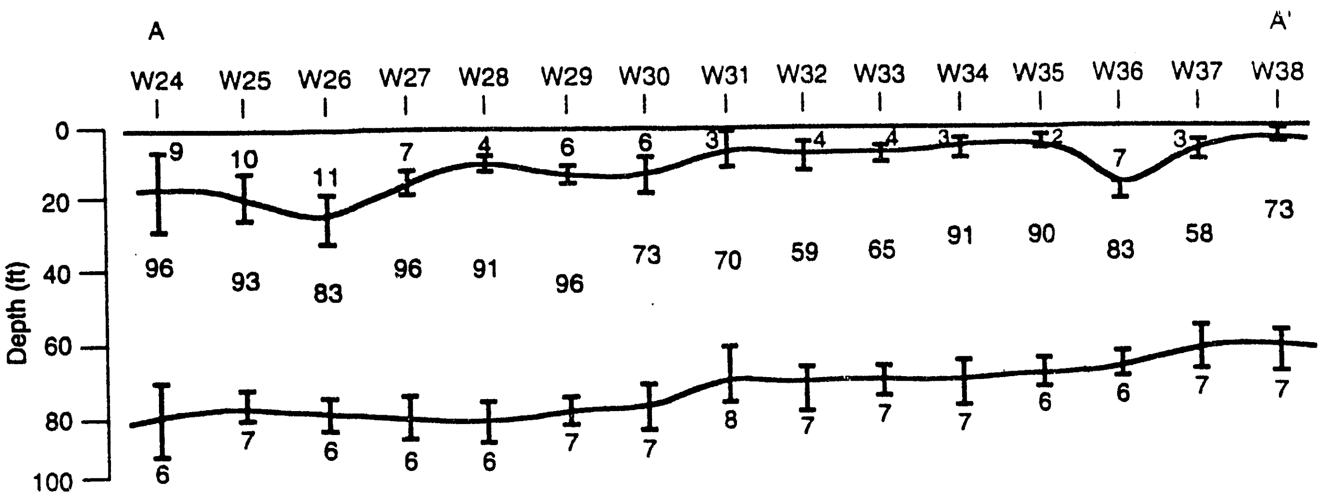

Figure 19. Conventional TDEM Profile (ohm-meters) at Waverly (Section A-A')

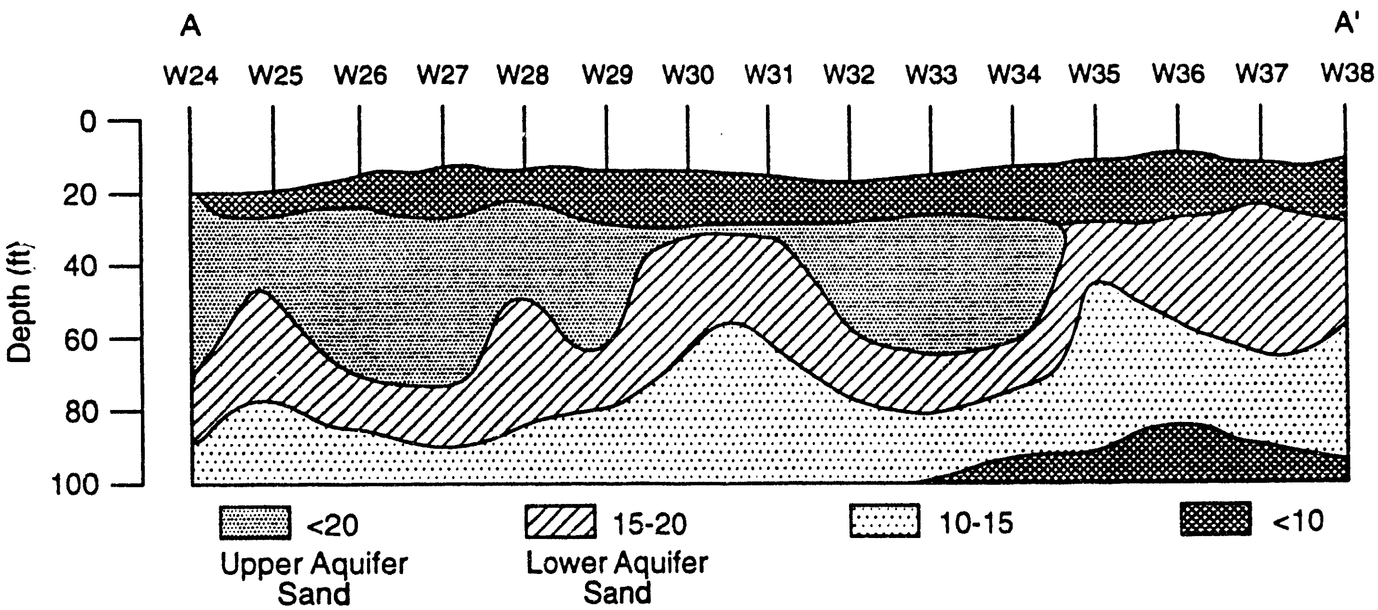

Figure 20. Image Inversion TDEM Profile (ohm-meters) at Waverly (Section A-A')

significant additional cost to the CCC/USDA, which was required to install modifications to the present system (an additional GWEX, piping back to the treatment plant, additions to the treatment plant, etc.), that should not have been incurred. In addition, wells to the northeast of the site would eventually have been contaminated by migration of the plume, resulting in potential health threats to individuals.

The Argonne field program for the additional SI was brief (approximately two months including report writing) and did not necessitate the installation of permanent monitoring wells. The use of multiple methodologies allowed the aquifer system northeast of the site to be understood with only temporary intrusion into residential and agricultural areas.

Murdock, Nebraska, Site

Site Setting and History

The CCC/USDA operated another grain storage facility at Murdock, Nebraska, approximately 22 mi north-northeast of Lincoln and the Waverly, Nebraska, site discussed above. Carbon tetrachloride was found in the public water supply at Murdock in 1985 (636 ppb), and an Immediate Removal Action was initiated by the EPA. The CCC/USDA accepted responsibility for the groundwater contamination and signed an Order on Consent Agreement in 1991, in which the agency agreed to evaluate remedial actions for the Murdock site. The general location of Murdock and the former CCC/USDA site are shown in Figure 23. As part of an ongoing program for the CCC/USDA, Argonne was asked to evaluate previous SI data for the Murdock site to determine if additional site characterization was required for correct evaluation of remedial alternatives.

The ESC Process

Evaluation of Existing Data. Various SIs of the Murdock area were carried out after the initial identification of the problem in 1985 and the Immediate Removal Action in 1986 and early 1987 (Ecology and Environment, 1986; Woodward-Clyde, 1987; CH2MHill, 1988a, 1988b). The primary objectives of these studies were to outline the contaminant groundwater plume, to determine the flow direction of the aquifer, and to ascertain whether a soil source was present at

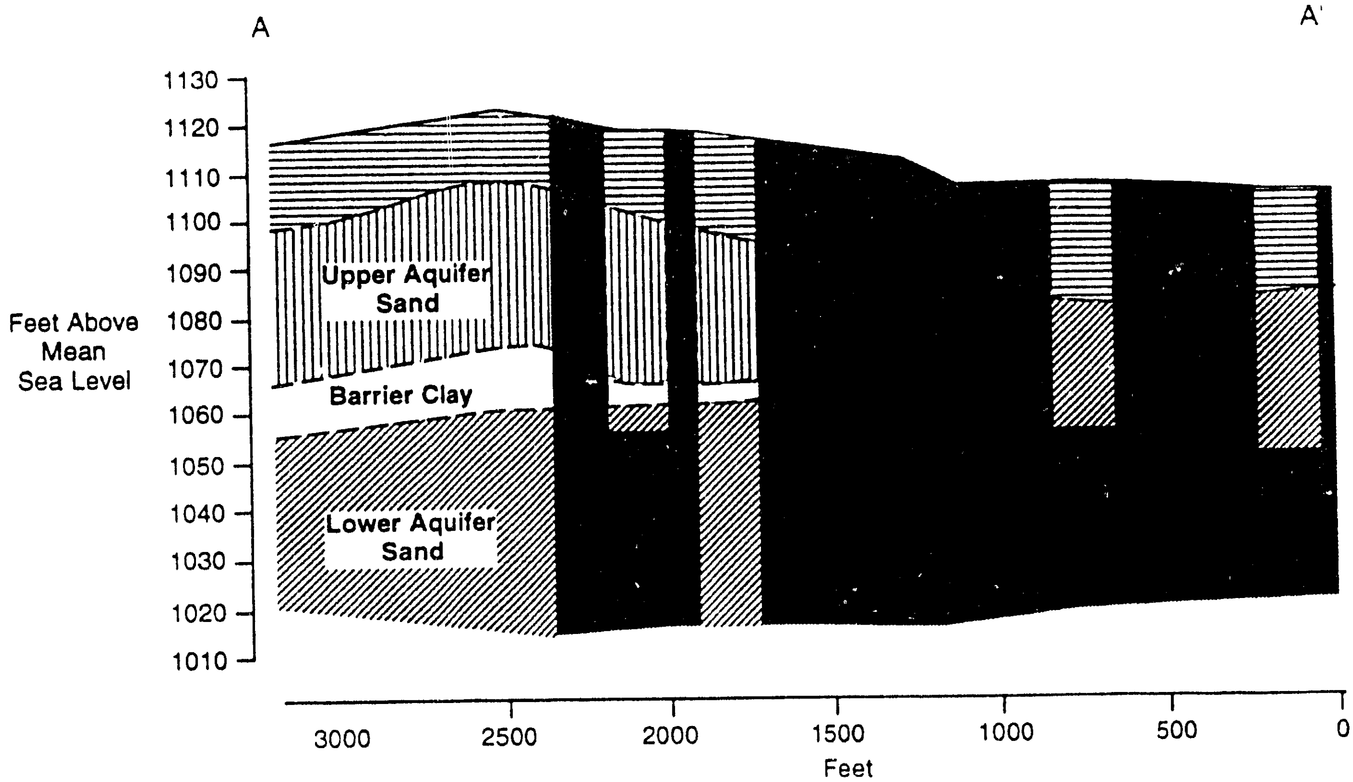

Figure 21. Pinchout of the Upper Aquifer at Waverly, as Interpreted from TDEM Data, Geochemistry, and Geology

the former CCC/USDA site, all for the purpose of evaluating and selecting remedial options. No soil source was found at the former CCC/USDA site. Major results from previous investigations of the groundwater plume are given below.

The first investigation used soil gas measurements to indicate the direction of movement of the groundwater plume and to guide the installation of monitoring wells. However, the assumption that surface soil gas measurements can be used to indicate the behavior of contaminants in groundwater at depth is flawed. The many factors affecting soil gas values (soil moisture, soil type, geologic features, temperature, Henry's law) invalidate their use as indicators of plume movement at depth. In addition, review by Argonne of the soil gas procedures used at Murdock demonstrated that the both the data collection and analytical procedures were performed incorrectly. Unfortunately, monitoring wells were installed on the basis of a northeasterly flow direction for the plume and aquifer, based on the results of the soil gas investigation (Figure 24).

Four pairs of monitoring wells (one well in each pair shallow at about 30-55 ft and one deep at about 80 ft) were installed, and one set of groundwater samples was collected from each. Samples from only one pair of wells tested positive for carbon tetrachloride; samples from the other three pairs of wells were negative. On the basis of these results, a theoretical model was derived for the plume at Murdock with a flow direction to the west-northwest (Figure 25), much different from the direction deduced from the soil gas survey.

Given these conflicting and questionable results from the previous SIs at Murdock, the CCC/USDA requested Argonne to design an ESC program for the site that would generate data adequate for evaluation and possible design of a remedial system. Although this ESC study encompassed several technologies, much like the Waverly ESC study discussed above, only one aspect of the Murdock ESC program will be discussed here.

Plume Delineation. One of the major objectives of Argonne's ESC program is to advance the use of subsurface groundwater sampling techniques that do not require installation of monitoring wells. Normally, numerous samples are required to completely and accurately define the lateral and vertical extent of nonconductive contamination within an aquifer. Generating these data with the monitoring well approach requires a massive number of wells. A monitoring well under CERCLA guidelines is limited to a 10-ft screen. Therefore, a 50-ft-thick aquifer requires five wells to accurately sample the vertical distribution of contaminants at one location. The average cost of monitoring well installation is \$120/ft, and each well requires approximately three days to complete. Attempts to accurately map groundwater contamination during site characterization with this approach are prohibitively expensive and time consuming. Hence, Argonne sought to use a more cost- and time-effective approach to obtaining groundwater samples without monitoring well installation.

Argonne used geologic reconstructions, geophysics, and geochemistry in the first phase of the ESC program at Murdock to constrain and prioritize the sampling program. The results of these studies indicated only one aquifer flowing to the north-northwest at Murdock. The aquifer is semiconfined beneath the former CCC/USDA site but becomes unconfined to the north.

The aquifer was sampled both laterally and vertically for contamination during the second phase of the ESC. Two

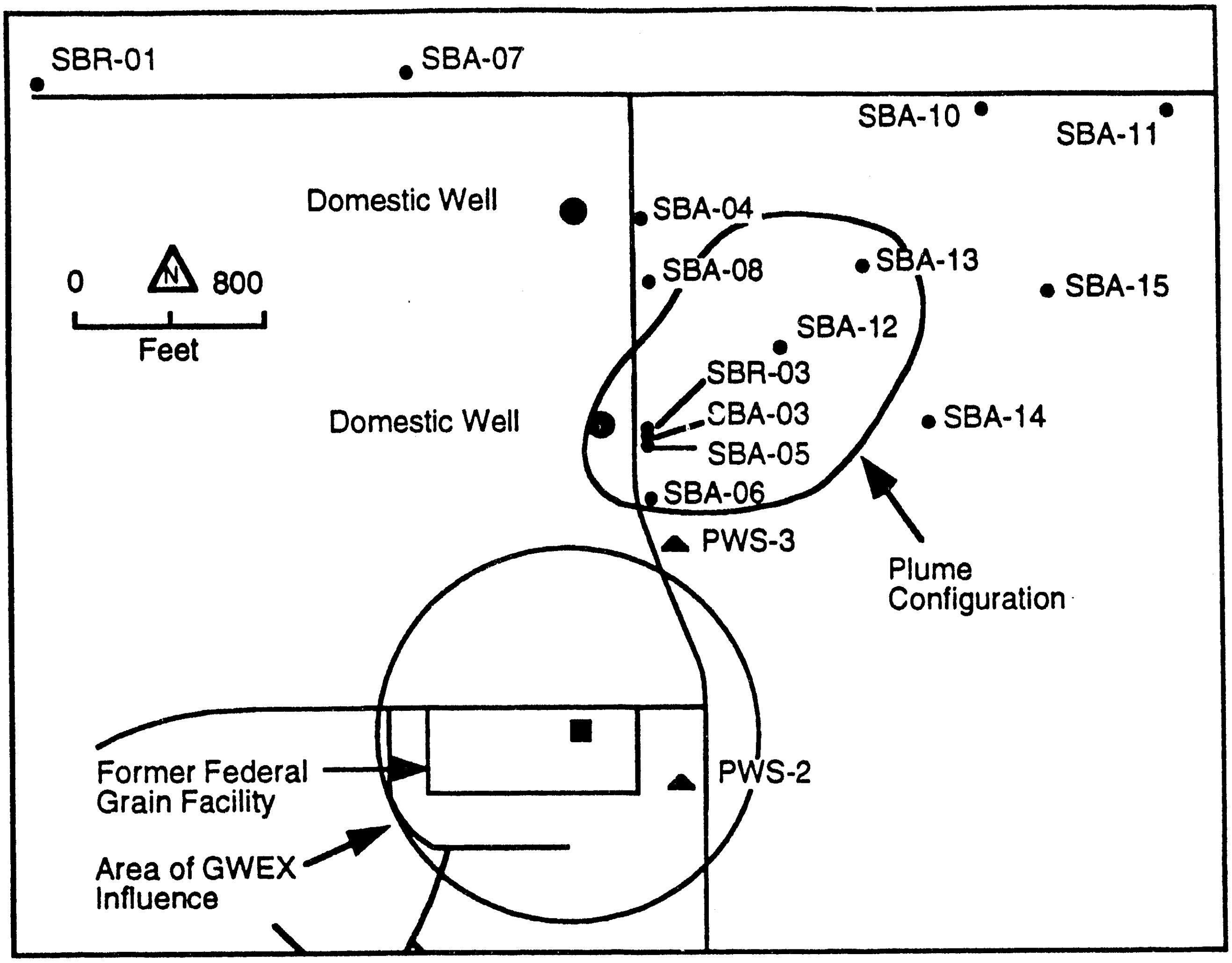

Figure 22. Configuration of the Contaminant Plume at Waverly

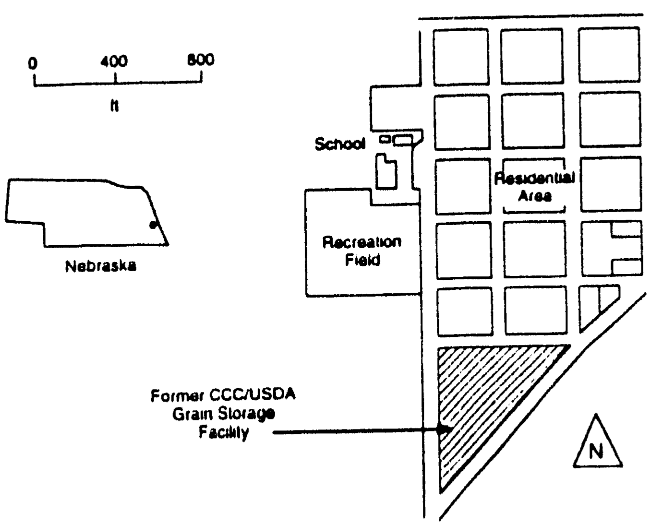

Figure 23. General Location of the Former CCC/USDA Site at Murdock, Nebraska

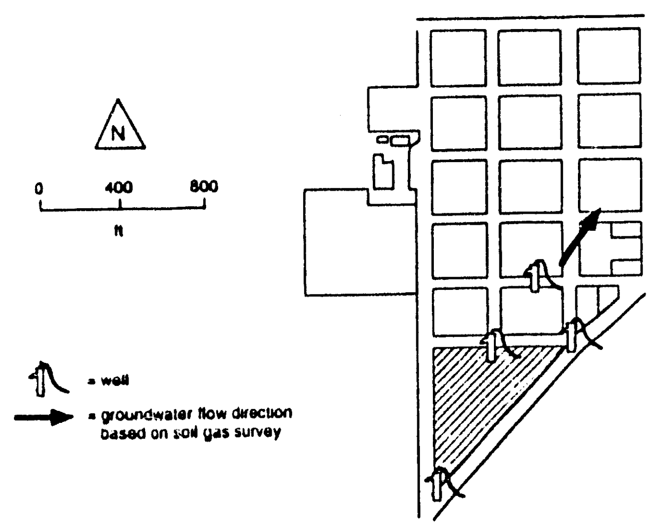

Figure 24. Presumed Direction of Groundwater Flow at Murdock, as Determined by Soil Gas Studies, and Subsequent Locations of Monitoring Wells

sampling techniques (hollow-stem auger with an attached HydroPunch and an electronic cone penetrometer [ECPT] with either the HydroPunch or bailer) allowed the rapid delineation of both the vertical and lateral extent of the plume without installation of monitoring wells. Argonne appreciates the cooperation of EPA Region VII in accepting these groundwater samples as equivalent to monitoring well samples.

Figures 26 and 27, respectively, show the lateral and vertical extent of the carbon tetrachloride plume at Murdock. The plume outlined by the Argonne ESC studies was confirmed by positive carbon tetrachloride results in water samples collected where the plume exits into a creek at the northern edge of the town. The plume distribution and flow direction predicted by the ESC are much different from those predicted by the earlier studies. The ESC program generated sufficient control data on the distribution of carbon tetrachloride in the aquifer to allow the CCC/USDA to make accurate evaluations of remedial alternatives.

Cost and Time Comparisons for the ESC Aquifer Sampling Methodology versus Monitoring Well Installation. A cost and time analysis comparing the subsurface sampling approach of the Murdock ESC to the traditional approach of monitoring well sampling was made to illustrate the advantages of the ESC. The following data were used in constructing the cost comparison: (1) During the ESC program, 84 aquifer samples were obtained. (2) The depth to the aquifer at Murdock is approximately 55 ft, and the aquifer

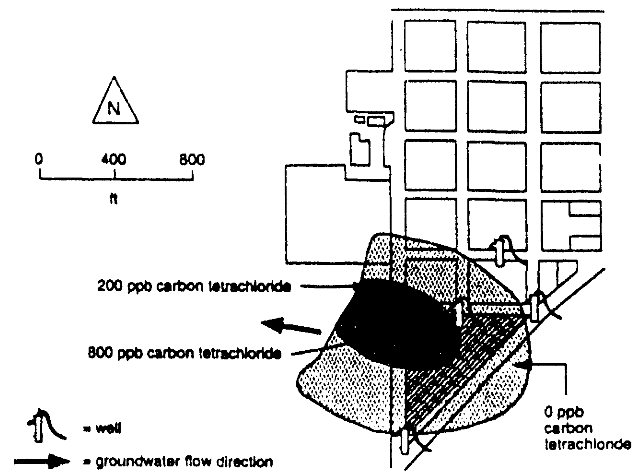

Figure 25. Theoretical Plume Model and Groundwater Flow Direction for Murdock, Based on Monitoring Well Data

is approximately 30 ft thick. An average depth of 70 ft was used in determining monitoring well costs. (3) The average cost for monitoring well installation is $120/ft, and the time is approximately three days including development. (4) One sample per monitoring well is assumed for equivalence with ECPT and hollow-stem auger sampling. (5) No costs for professional staff were included in the comparisons. Costs were limited to drilling contractor estimates and the actual

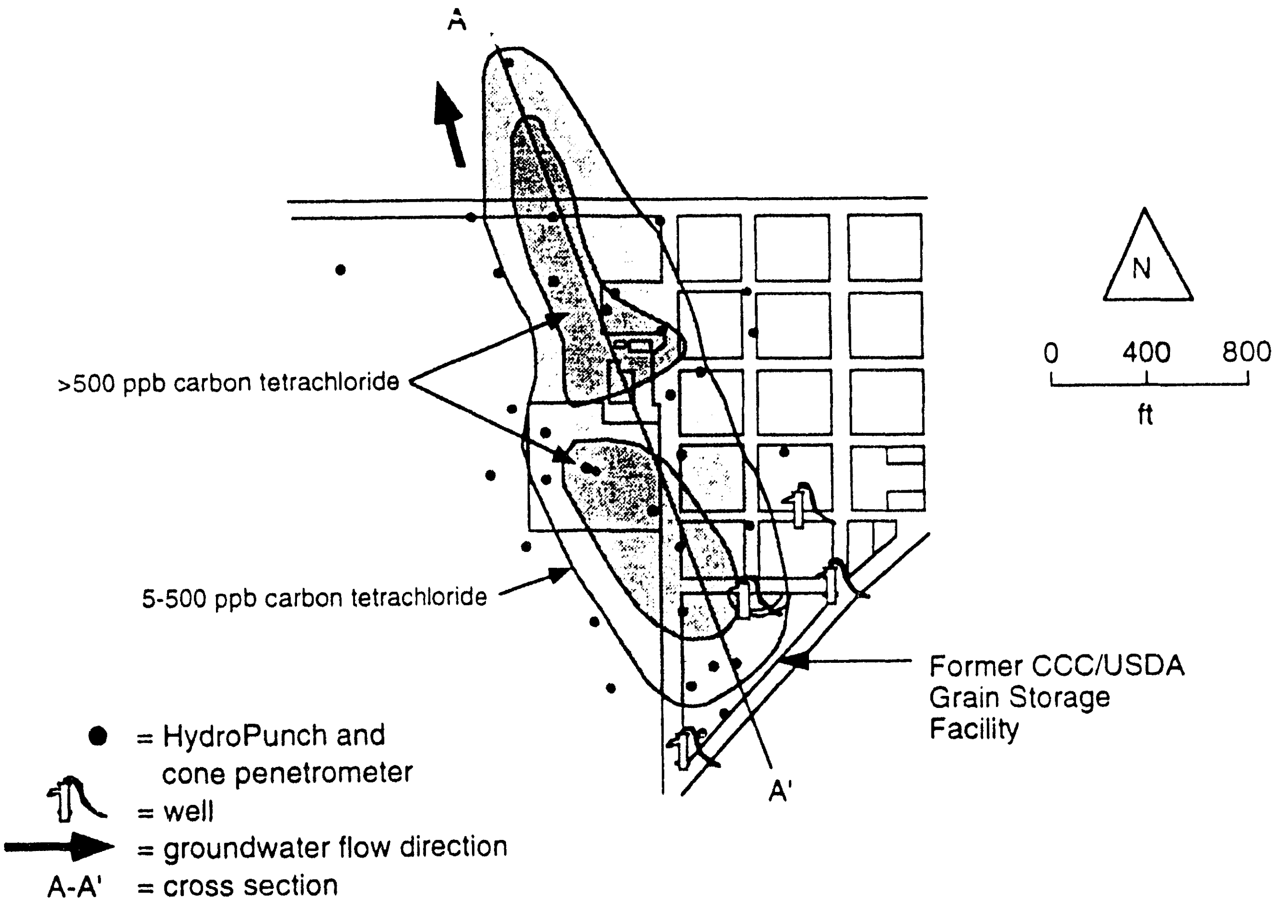

Figure 26. Lateral Extent of the Contaminant Plume at Murdock, as Measured by Argonne with the HydroPunch and Cone Penetrometer

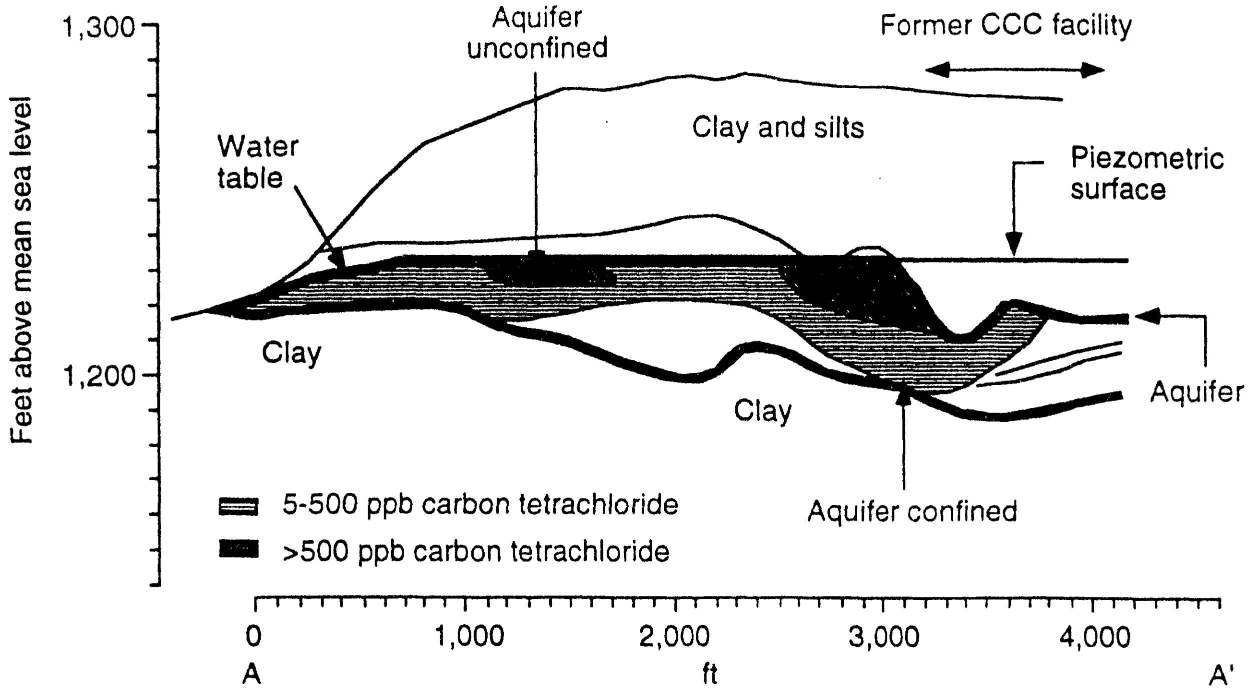

Figure 27. Vertical Extent of the Contaminant Plume at Murdock, as Determined by Argonne with the Hydropunch and Cone Penetrometer

costs of the ECPT and hollow-stem auger contractors plus equipment. (6) Comparisons include costs for sample analysis by a Contract Laboratory Program laboratory at Level IV quality.

The actual cost of the ESC groundwater sampling and analysis program was $200,000, and 16 field days were required. The estimated cost and time for the monitoring well approach for sampling and analysis of the same number of aquifer samples at Murdock are $1,000,000 and 252 days. Therefore, the cost of the ESC method is approximately 1/5 that of the monitoring well approach, while the time is approximately 1/15. At sites where the aquifer is thicker, cost differences would be even more pronounced.

At another CCC/USDA site in Utica, Nebraska, the aquifer is 60 ft thick. For this site, the actual cost of the first phase of the ESC was $175,000, and the time for completion was 10 days. The guidelines above were used to estimate the monitoring well costs at $1,750,000 for an equivalent number of groundwater samples. Thus, the cost of the ESC approach is 1/10 that of the standard monitoring well approach for Utica. The time required for installation of monitoring wells was estimated at 288 days, for a time differential of 1/28 in favor of the ESC approach.

More importantly, in addition to efficiency of cost and time, the ESC approach produces a better technical product. Monitoring wells are usually placed sporadically within the aquifer during site characterization. Therefore, complete sampling of the aquifer is seldom achieved because of cost constraints. The ESC approach allows for complete sampling and achieves the needed cost and time savings.

Discussion

Previous site investigations at Murdock were unsuccessful in accurately delineating the carbon tetrachloride plume. The ESC methodology allowed for rapid and accurate delineation of both the vertical and lateral extent of the plume without the installation of monitoring wells. The ESC approach not only generated better technical data but resulted in significant cost and time savings for the CCC/USDA.

SUMMARY AND CONCLUSIONS

The ESC methodology has been demonstrated to be a time- and cost-efficient process for producing high-quality preremedial site characterizations. The ESC methodology is based on a scientific approach to problem solving that allows regulatory guidance to be easily incorporated. In other words, science drives the program within a regulatory framework. This methodology differs from attempts to follow a regulatory guidance document without incorporating a scientific approach. Such attempts have too often been made in environmental site investigations; they have probably been the major reason for the technical failure of many previous programs.

The ESC process is flexible and neither site nor contaminant dependent. The process has been successfully tested and applied in SIs of multiply contaminated landfills in New Mexico (for the BLM) and at former grain storage facilities in Nebraska and Kansas, contaminated with carbon tetrachloride (for the CCC/USDA). Argonne's preremedial site investigations based on the ESC approach have been accepted by the appropriate regulatory agencies.

The ESC is a process and not a specific technology. Technologies are incorporated as required by the problem to be solved. Whenever possible, existing available technologies and methodologies are used for the program. However, Argonne has used the ESC process as a platform for adaptation, development, and testing of new technologies, because the program incorporates a multiple-technology approach that allows rapid verification and testing of new concepts.

ACKNOWLEDGMENT

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