Plume Capture During Construction

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Groundwater contamination can affect significantly construction activities in areas of the country where the depth to groundwater is relatively shallow. An innovative method of controlling groundwater contamination plumes during construction to prevent worker exposure to the contaminants and exacerbation of the contaminant plume is presented. Application of this method can reduce delay claims, injuries, and potential litigation related to the contamination. The plume capture principles were applied successfully at two sites with petroleum hydrocarbon groundwater contamination adjacent to a dewatering project in Orlando, Florida. Contamination plumes were decreased greatly after plume capture, with no exacerbation of either plume.

Construction activities in areas with high groundwater often involve dewatering for installation of utilities, piping, and storm water control structures. The discovery of groundwater contamination in the area can affect the construction schedule since most roadway contractors are not equipped or certified to deal with exposure to contaminants. Initial impacts may include work stoppage, delay claims, and worker compensation claims. In addition, the parties responsible for the contamination may decide to sue if they can demonstrate that the plume was exacerbated. Exacerbation, in such cases, may be defined as enlarging or moving the plume from its preconstruction location. Any movement of this sort may prolong the time to remediate the site or require an increase in the number or size of equipment needed for remediation. Either possibility could increase substantially the cost of remediation.

In current practice, groundwater contamination usually is addressed if it happens to be discovered during the construction of a transportation project. However, many states have begun procedures to identify contamination in and adjacent to the construction right of way. The Florida Department of Transportation (FDOT) has formalized its contamination assessment procedures in Chapter 22, Part 2 of its *Project Design and Environment Manual.* This manual has served as the basis for preconstruction assessment activities for a number of states and countries. The institution of procedures similar to these greatly reduces the difficulty in addressing contaminated sites by allowing more time for avoidance or design and implementation of remedial measures.

A firm understanding of the principles of groundwater movement and control will allow a rapid response to the contamination. Two general situations may be encountered: the first, and most common, is construction through an area of groundwater contamination; the second is construction adjacent to but outside of an area of contamination. Both situations require that a preconstruction assessment be performed. The movement of the contaminated groundwater must be controlled so that the plume is not exacerbated during the project's progression.

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Groundwater control measures commonly used in both the construction dewatering and groundwater remediation industries include groundwater pumping from dewatering points and recovery wells; reinjection of water through well points, trenches, or galleries; and treatment of contaminated water by air stripping and granular activated carbon polishing. Applying these measures to groundwater contamination encountered during roadway construction can minimize the potential problems.

THEORY OF PLUME CAPTURE

Many equations can be used to predict groundwater movement and drawdown from recovery wells. Two of the oldest and most commonly used are the Theis equation and the related Cooper-Jacob nonequilibrium equation. The first applies to all pumping durations but, until the recent proliferation of computers, required the extensive use of tables to evaluate. The Cooper-Jacob solution requires a steady-state, long-term pumping scenario. Since most construction dewatering operations are short term, the Theis equation is recommended. It should be noted that most computer models assume steady-state conditions. It is recommended that the placement of recovery wells be determined using the Theis equation and then input into a model for verification.

Plume capture theory is based on established principles of hydraulics and groundwater movement. Dewatering creates a depression in the groundwater along the line of the well points. In a cross-sectional view, this depression is curved, with the deepest part at the well points and reaching a point of zero drawdown some distance away. A recovery well will produce a similar drawdown profile in a radial pattern around the well. If a recovery well is placed close enough to the required dewatering activities, the drawdown curves from the dewatering and the recovery well will intersect. The intersection point will be at a higher elevation than any other point along the drawdown curves. This intersection point is called the groundwater divide and theoretically represents the point across which groundwater will not move. Groundwater on the dewatering side of the divide will flow to the dewatering operation, whereas groundwater on the other side of the divide will flow to the recovery well. The theory of plume capture is to place one or more recovery wells in a position to create a groundwater divide at a desired location between the dewatering activities and the recovery wells to prevent movement of contaminated groundwater toward the dewatering.

APPLICATION OF PLUME CAPTURE METHODOLOGY

The first step in applying plume capture theory is to evaluate the possibility of not using plume capture at all. Simpler and less expensive alternatives include changing the design, working in the wet, and using sheet pile. Changing the design may be possible if the contamination is detected early enough in the construction process. Design changes to avoid contaminated conditions include raising the invert of drainage structures and pipes and moving the piping or structure locations. Working in the wet (i.e., not dewatering) is possible if the construction does not extend more than 0.7 to 1 m (2 to 3 ft) below the water table. Sheet piling is commonly used to provide sidewall stability in excavations and to limit the amount of pumping required to dewater. It can also be used to limit the movement of a plume.

If design changes are not possible or will not address fully the groundwater contamination, a plume capture system must be designed and implemented. The process of designing a plume capture system starts with a complete assessment of the proposed work, site, extent of contamination, and aquifer properties in the area.

Construction Project and Site Assessment

A complete understanding of the scope of the construction and dewatering work obviously is essential. The design plans must be reviewed to determine the depth and location of the proposed piping and structures, as well as the location of all existing utilities and other obstructions. If the construction will be taking place through a groundwater contamination plume, it may also be necessary to modify the design to prevent the contaminants from migrating through the backfill after construction has been completed. The dewatering contractor must be consulted to determine the expected well point locations, pumping rate, radius of influence, and duration of the dewatering activities. A site visit should be conducted to verify the locations of any utilities or obstructions, ascertain other potential sources of contamination, and identify possible treatment compound locations and effluent discharge options. The availability of electric power and water at the potential compound locations and the presence of any existing monitor wells or groundwater treatment systems should also be noted.

Plume Assessment

Regulatory agency files should be reviewed to obtain information on the previously known location and concentration of the groundwater contamination. These files may also contain information about the aquifer characteristics, and the design of the treatment system.

In addressing plume exacerbation, it is essential to define the horizontal and vertical extent of the contamination. Existing monitor wells may be used or temporary wells installed. It is preferable to delineate fully the areal extent of the plume; however, access to properties adjoining the right of way may be denied. In this case, the contamination underneath the roadway and right of way should be defined. The purpose of the plume assessment is to provide a baseline plume configuration and a basis for estimating influent concentrations into the treatment system.

Aquifer Assessment

An understanding of the aquifer characteristics at the site is necessary for designing the plume capture system. The properties of interest are the transmissivity (or hydraulic conductivity and saturated aquifer thickness), hydraulic gradient, and porosity or specific yield. In order of preference, these may be obtained by evaluation of data from an existing recovery well, a short-term pump test on a recovery well, slug tests on monitor wells, and typical values from geologic literature.

Plume Capture Design

The first step in designing a plume capture system is to estimate the radius of influence form the dewatering system, expected radius of influence from a recovery well, and pumping rate necessary for plume capture and creation of a groundwater divide. Dewatering shorter sections of trench will reduce the required pumping rate and reduce the radius of influence from the dewatering, both of which are beneficial from a plume capture standpoint. The design objective for the recovery well(s) is to create a groundwater divide at a selected location. In situations where the construction will take place outside of the contaminant plume, the divide should be located between the plume boundary and the construction site. Otherwise, the divide should be located so that the minimum plume area is disturbed. Use of sheet piling will help in creating the divide, although it is not totally effective in preventing groundwater movement and cannot be used in areas with rock or underground utilities. Reinfiltration of a portion of the treated water through appropriately placed well points, ditches, trenches, or galleries to create a mounding effect in the groundwater will also help to establish and maintain the groundwater divide in the desired location. Once the general drawdown contours and the location of the groundwater divide have been calculated using these principles, the results should be entered into a groundwater flow model to verify the results and present them graphically.

Treatment System Design

A complete description of the design process for a groundwater treatment system is beyond the scope of this paper. The two most commonly used treatment methodologies are air stripping and granular activated carbon adsorption. They may be used alone or in combination to treat the flows from the dewatering operation and the recovery well.

The design effluent concentration is generally equal to or less than the drinking water standard for the contaminants, although this may vary depending on the selected disposal method. Disposal options for the effluent include reinfiltration between the recovery and dewatering systems to help create a groundwater divide, reinfiltration away from the plume, injection wells, sanitary sewer, storm sewer, and discharge to surface water. Each option has differing permit conditions that must be met. The final treatment system design must contain the flexibility to be adjusted to field conditions once the plume capture operation has begun.

Plume Capture System Startup

The plume capture system should be installed and tested before the dewatering begins. This will allow evaluation of the actual influent concentrations and the radius of influence of the system and will ensure that the equipment has been installed and is operating properly. The system can then be adjusted as necessary to provide adequate capture and treatment of the groundwater.

Plume Capture System Operation

The plume capture system must start up before the dewatering activities begin at the site. Establishing the cone of influence of a recovery well is not an instantaneous process. The more time available before dewatering, the better the results will be. Plume capture should also continue until after the dewatering is completed for similar reasons.

While the system is operating, water levels must be monitored regularly to ensure that the groundwater movement is being controlled. Influent and effluent samples must be collected to verify the treatment efficiency and to provide enough time to adjust the treatment system if the influent concentrations begin to increase. Samples should also be taken from selected monitor wells at regular intervals to monitor any changes in the plume configuration. The most rapid and convenient method for providing the analytical data is through a mobile laboratory. If mobile facilities are not available, a fixed-base laboratory should provide rapid-turnaround analyses.

Project Completion

A plume capture project is completed by resampling all monitor wells to determine the postconstruction plume configuration. This configuration is then compared with the baseline plume configuration to demonstrate that the plume was not exacerbated as a result of the construction activities. A final report typically is prepared to document these results for future reference.

CASE STUDY

The Goldenrod Road project in Orlando, Florida, is presented as a case study. FDOT planned to conduct dewatering operations to place storm sewer piping in conjunction with road construction along Goldenrod Road in June 1994. Two retail gasoline facilities with known groundwater contamination were identified at the intersection of Lake Underhill Road and Goldenrod Road. The two facilities were located on the southeast and southwest corners of the intersection, Sites 1 and 2 respectively, as shown in Figure 1.

Construction Project and Site Assessment

The proposed dewatering activities were to take place along the eastern side of Goldenrod Road, adjacent to Site 1. The design dewatering rate, as provided by FDOT's dewatering contractor, was to be no more than 5.2 L/sec (83 gal/min). The intent of the dewatering was to depress the water table approximately 3 m (10 ft) in order to facilitate installation of the storm sewer piping. Sheet piling was to be installed adjacent to Site 1 for sidewall stability during excavation. Sheet piling was not planned for the west side of the road because of the presence of underground utilities.

All structures at Site 1 had been demolished and the underground storage tanks removed. Five monitor wells were located on-site. No other facilities were available.

Site 2 was an active retail gasoline facility. Seventeen permanent monitor wells were located on-site, and a groundwater treatment system had been installed. The system consisted of three recovery wells, an air stripper, and an infiltration gallery. Because of problems with the infiltration gallery flooding, the system was operating at only 0.2 L/sec (3 gal/min) from one recovery well. A drainage ditch discharging to a storm sewer surrounded the east, north, and west sides of the site.

Plume Assessment

Contamination assessment reports for both facilities were obtained from a review of regulatory agency files. A small groundwater contamination plume was reported to extend north from the former tank pit area at Site 1. Groundwater contamination at Site 2 reportedly underlaid most of the northern portion of the site. Additional assessment work was performed in May 1993 to confirm these reports.

The existing plume conditions at Site 1 were determined through installation and sampling of five additional monitor wells in the right of way along the north and west property boundaries. The highest concentrations—384 parts per billion (ppb) benzene, 1,032 ppb total volatile aromatics—were found in one well on the western edge of the site. Trace amounts of hydrocarbons were found in two wells along the north property boundary. Further investigation was not possible because of the construction schedule.

The baseline plume configuration at Site 2 was determined by sampling all monitor and recovery wells. The results confirmed that the plume was centered on the north pump islands, in the north-central portion of the site. The highest concentrations detected—1688 ppb benzene, 2,064 ppb total volatile aromatics, 786 ppb methyl tertiary-butyl ether (MTBE)—were found in a well adjacent to one of the pump islands.

Aquifer Assessment

The groundwater flow direction was to the east-northeast, as determined from measuring water levels in monitor wells. The rest of the aquifer characteristics were obtained from a review of the previously prepared contamination assessment reports and an evaluation of the operating recovery system at Site 2.

Plume Capture Design

The impact of the dewatering on the contamination at Site 1 was impossible to predict because the contamination plume was not well-defined. The highest concentration found on-site was immediately next to the dewatering operation. The sheet pile would restrict plume movement, but complete prevention of any movement was deemed impossible. The plume capture design for Site 1 therefore addressed only treatment of the dewatering discharge to prevent spreading the contamination and the trace contamination along the northern portion of the property. One recovery well was installed in this area to capture the known extent of this plume.

The design of the plume capture system at Site 2 concentrated on keeping the plume boundaries on the site. The existing recovery and treatment system was inadequate to create a groundwater divide

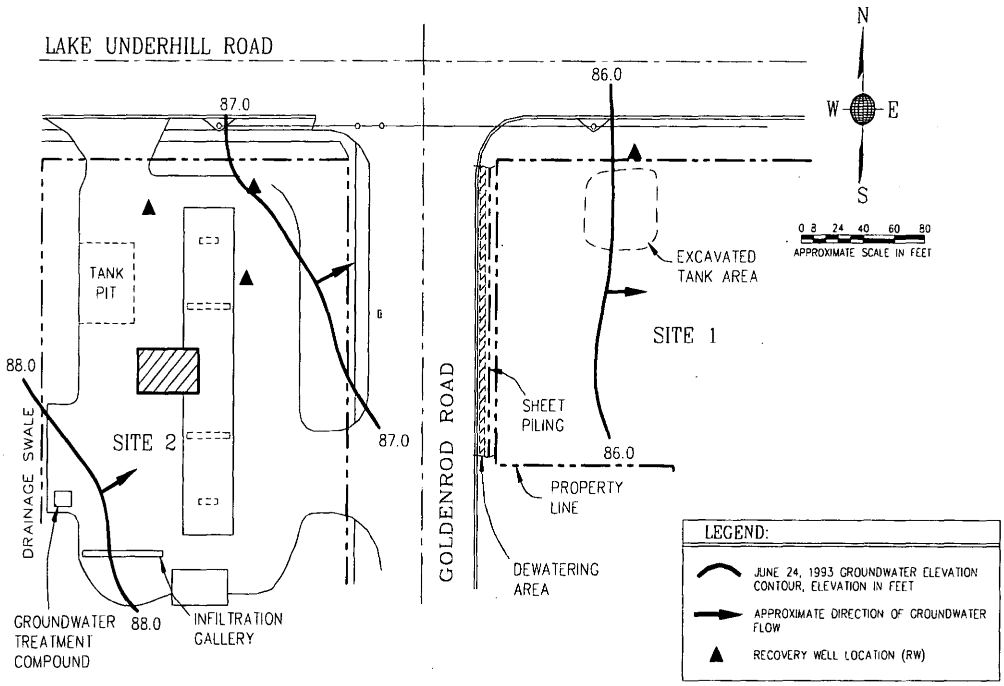

FIGURE 1 Site plan and June 24, 1993, groundwater elevation map.

along the property line. The final design used two of the three existing recovery wells, fitted with larger pumps, to create a groundwater divide along the eastern property boundary. The groundwater treatment system was located adjacent to the existing system, and the existing piping used to transport the recovered groundwater. The outlets from the drainage ditch surrounding the site to the storm sewer were raised temporarily with sandbags to maintain approximately 1 m (3 ft) of water in the ditch. The treated effluent was discharged to the ditch, where a portion of the water infiltrated and helped create the groundwater divide.

Treatment System Design

Two separate treatment systems were required because of the construction taking place in the roadway between the sites. Carbon adsorption was selected as the treatment methodology for both systems because of the relatively low flow rates and expected concentrations. The expected flow rates were 7.25 L/sec (115 gal/min) for the combined flow from the Site 1 recovery well and the dewatering discharge and 2.5 L/sec (40 gal/min) total from the two recovery wells at Site 2. Two 4540-kg (10,000-lb) carbon cells were used at Site 1, and one 900-kg (2,000-lb) cell was used at Site 2. The cells were designed to produce an effluent with no detectable contaminant concentration. The design was approved orally by the Florida Department of environmental Protection (FDEP). FDEP personnel has been contacted at project inception and had been kept informed of progress during the assessment and design activities. This close coordination greatly facilitated the design approval and implementation.

At system startup, it was determined that the recovery wells at Site 2 could produce only about 0.6 L/sec (10 gal/min) each and that the dewatering flow rate had increased to approximately 12.6 L/sec (200 gal/min). The treatment system was capable of handling these flow rates without change. The Mobil recovery wells appeared to produce an adequate drawdown to create the groundwater divide, so no design changes were needed. The plume capture system was started on June 24, 1993, 4 days before the dewatering activities in the area began.

Results

Figures 1 through 7 illustrate the results of the plume capture effort. Figure 1 shows the groundwater flow immediately before starting the plume capture system. Flow is uniform to the east-northeast. Figure 2 shows the groundwater flow with dewatering taking place next to the sites. The cones of influence are apparent around the two recovery wells at Site 2. Groundwater flow from Site 1 has been reversed and is now flowing to ward the dewatering area. Figure 3 shows the change on the following day. The cones of influence around the Site 2 recovery wells have increased, and a distinct cone has formed around the Site 1 recovery well. The groundwater gradient at Site 1 is essentially flat, with a slight trend in the easterly direction. Figure 4 illustrates the groundwater flow after the dewatering has moved north of the area. The gradient is returning to the normal east-northeast direction but is still clearly influenced by the dewatering to the north. Figures 5, 6, and 7 show the pre- and post-construction benzene, total volatile aromatic, and MTBE concentrations at the two sites.

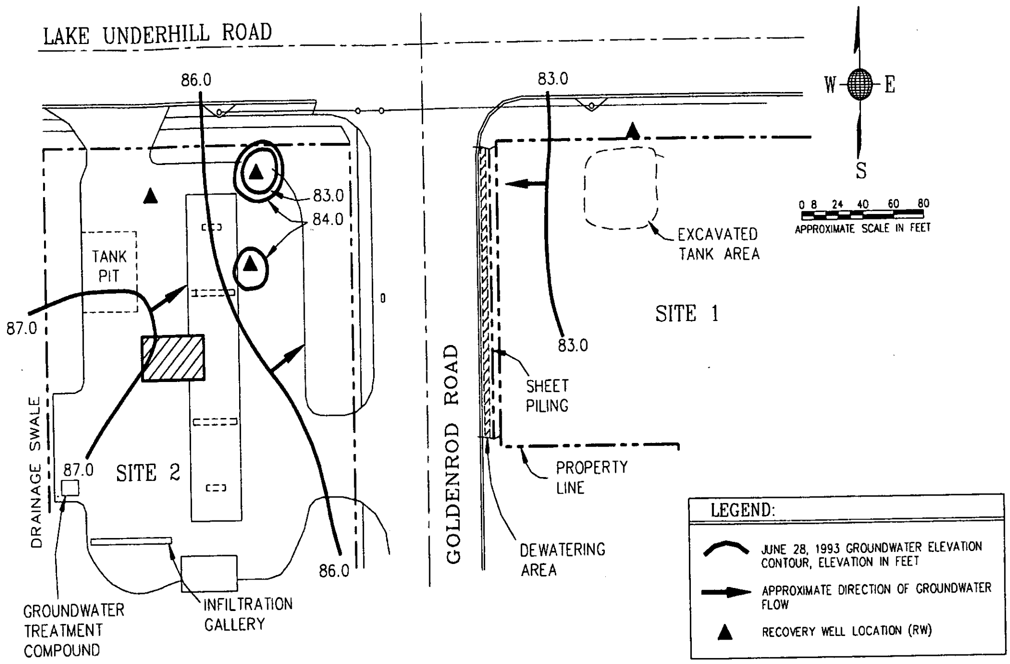

FIGURE 2 **June 28, 1993, groundwater elevation map.**

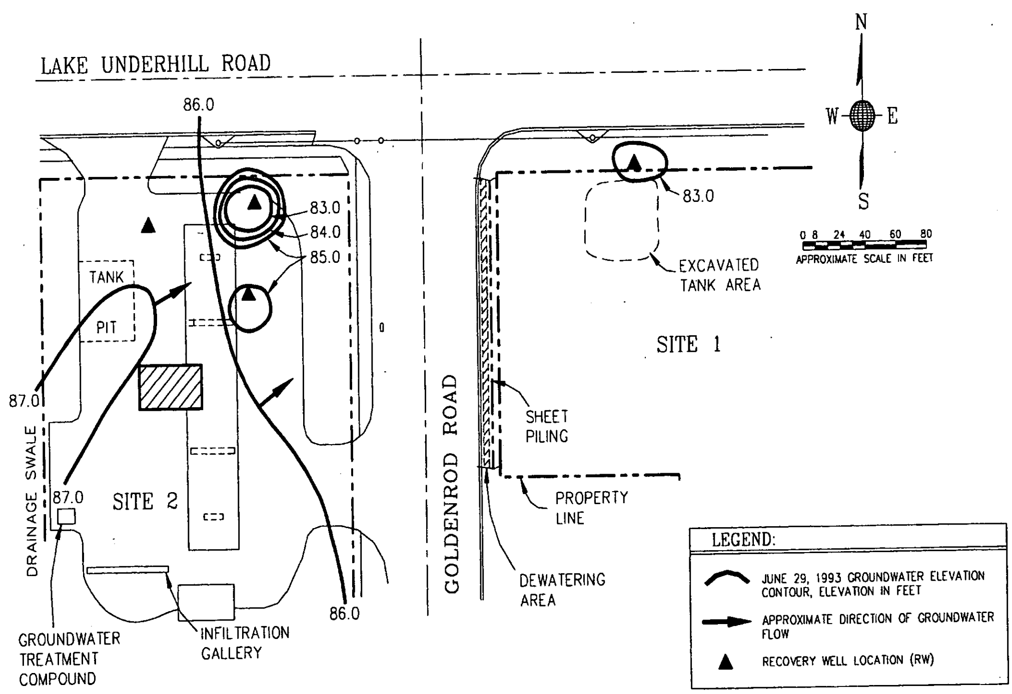

FIGURE 3 **June 29, 1993, groundwater elevation map.**

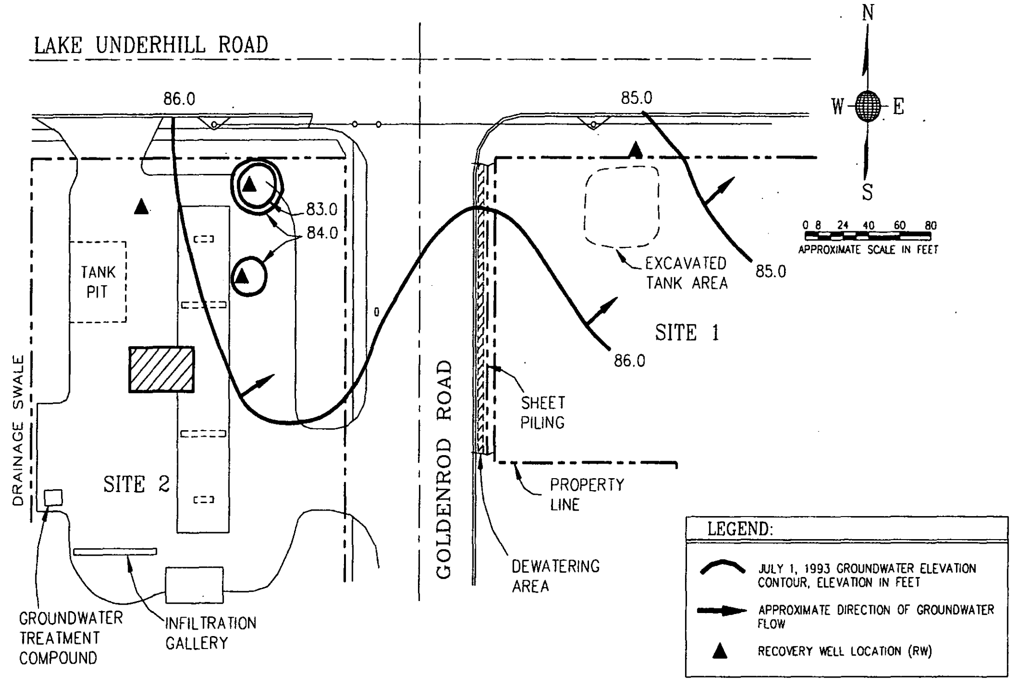

FIGURE 4 July 1, 1993, groundwater elevation map.

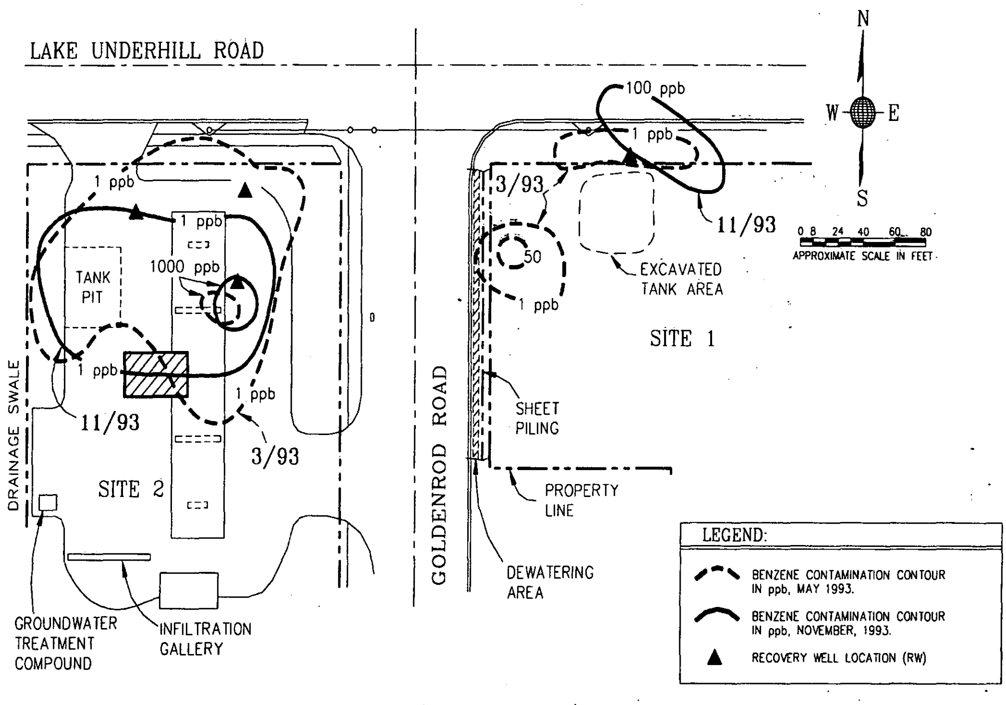

FIGURE 5 Pre- and postconstruction benzene concentration map.

The contamination plume at Site 2 was significantly smaller after the construction than before. The contamination found on the west side of Site 1 was removed completely by the plume capture and dewatering operation. The contamination on the north property boundary remained and it increased in concentration. The previously reported contamination north of the site had clearly migrated underneath Lake Underhill Road. The plume capture activities pulled the plume back to Site 1, which was not regarded as exacerbation of the contamination.

In summary, the plume capture system worked as designed. Neither plume was exacerbated—in fact, the contamination plumes at both sites were reduced significantly as a result. These same plume capture principles have been applied to other FDOT projects with similar successful results. Plume capture therefore is recom-

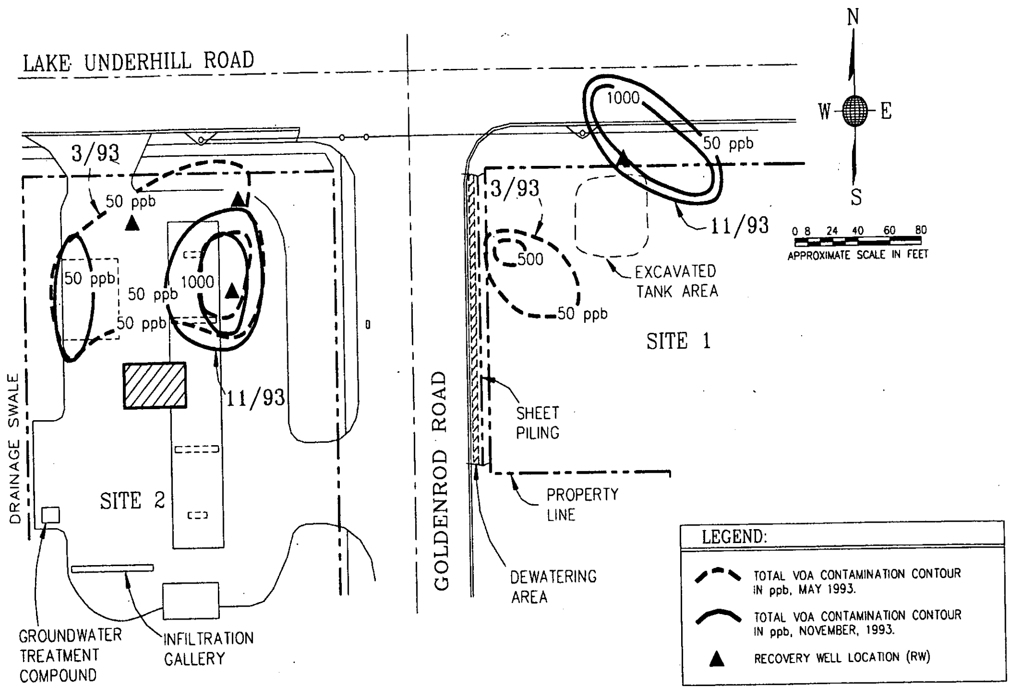

FIGURE 6 Pre- and postconstruction total volatile aromatics concentration map.

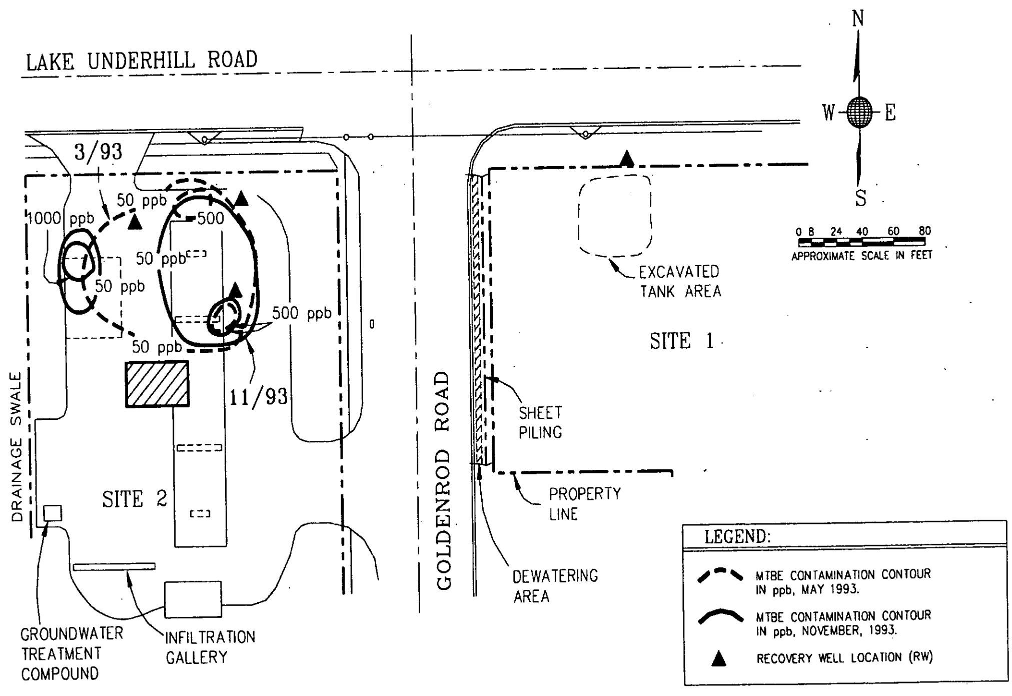

FIGURE 7 Pre- and postconstruction MTBE concentration map.

mended highly as a means of addressing groundwater contamination and reducing potential impacts to the construction schedule while protecting FDOT from the liabilities of exacerbation.

The total cost of the case study project was $200,000. FDEP petroleum reimbursement personnel indicate that the average total cost to remediate a petroleum contamination site, from assessment through postremediation monitoring, is approximately $250,000 and may range from $50,000 to more than $1 million. Contractor delay claims from work stoppages due to contamination usually range from $5,000 to $50,000/day. Attorney fees range from $100 to $300/hr and may approach $500,000 to litigate a complex case. Considering the potential exposure of the department to one or more of these costs, plume capture proves to be economically attractive as well.

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