

VERTICAL AND HORIZONTAL PURGING OF CONTAMINATED GROUNDWATER IN CONFINED SPACES

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(Received June 1, 1989; accepted September 11, 1989)

Summary

This paper presents the design and field application of a cost-effective, combined vertical and horizontal drainage system used to extract contaminated groundwater from a sand layer. The contaminated soil layer was located beneath a 15-cm (6 inch) thick, reinforced concrete slab within the confines of an industrial building. The designed purge system used for this project allowed for the effective drainage of the contaminants from soils while minimizing the area of slab to be removed and the need to excavate the entire volume of the contaminated aquifer. This paper presents background data on the site, including site restrictions and design details, implementation and field results of the purge system.

The purge system was used to drain chromium and trichloroethylene contamination. The design resulted in a 40% cost reduction over traditional remediation techniques which involve greater excavation and shoring requirements. Based on a mass balance of the contaminants, it was estimated that 96% of the chromium contamination was removed and 98% of the trichloroethylene contamination was removed.

It was estimated that the induced flooding reduced the remediation from 220 days to 180 days.

Introduction

The extraction and subsequent cleanup of contaminated groundwater can be an expensive process. Cleanup costs can vary depending on the approach adopted. Traditional approaches [1–3] such as:

- full excavation of all contaminated soils and drainage of all surrounding contaminated groundwater,
- steam injection and the subsequent thermal stripping of organic contaminants,
- injection of pre-heated air with the subsequent removal of organics, are commonly used for decontaminating groundwater and soils.

These approaches are generally:

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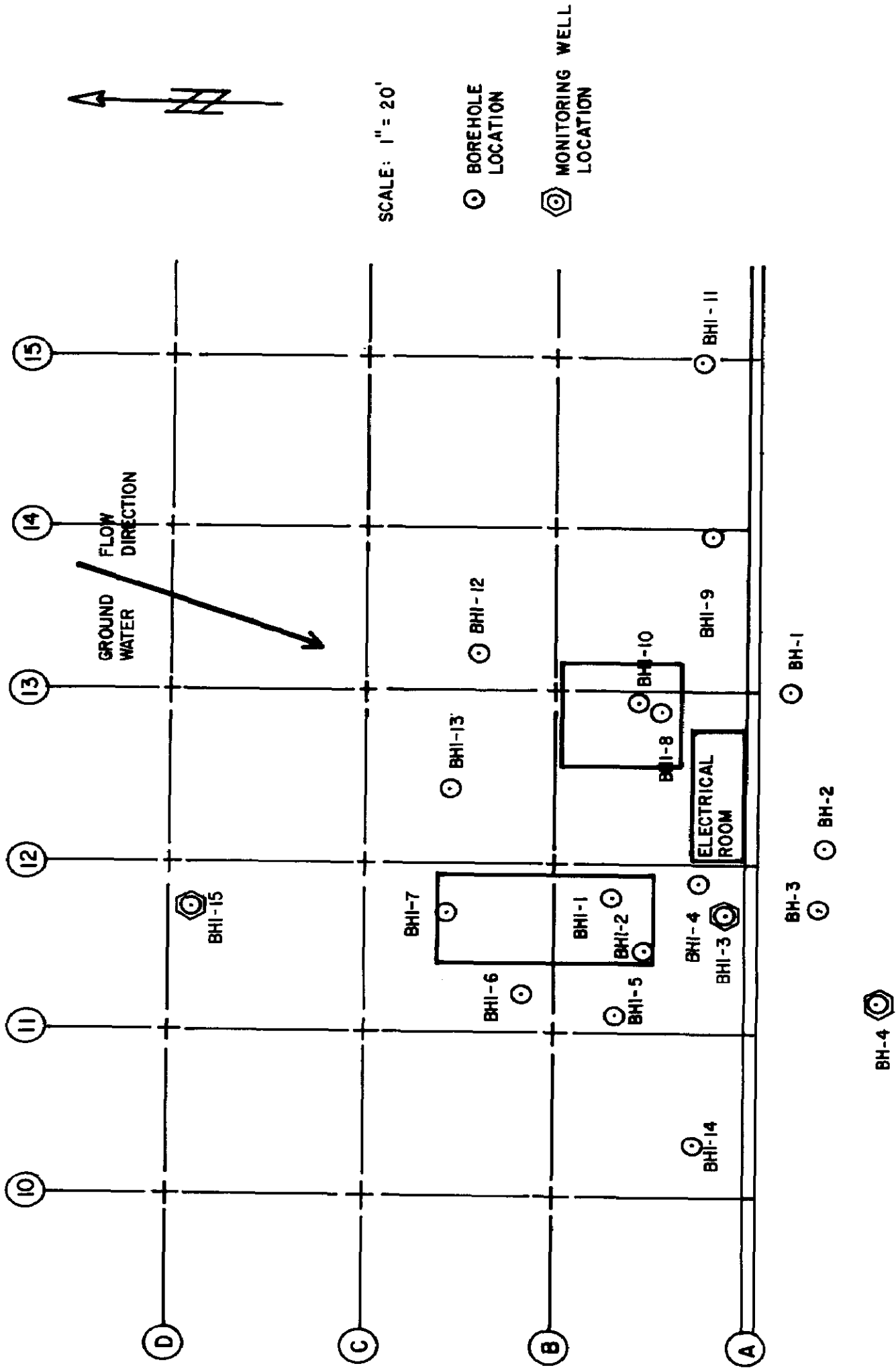


Fig. 1. General site plan.

- expensive,
- time consuming,
- limited to sites with high accessibility.

This paper describes a novel, cost effective approach developed and applied to decontaminate soil and groundwater from trivalent and hexavalent chromium species and trichloroethylene (TCE) which were confined beneath the floor slab of an industrial building.

Site background

Clayton Environmental Consultants, Ltd. was retained to investigate and decontaminate an area of soil and groundwater from chromium and trichloroethylene.

The client's operation included the production of nuts and bolts with subsequent treatment in several below-floor pits. One of the pits was used for the neutralization of chromic acid before the effluent was discharged to the sanitary sewer. A detailed investigation of the facility, traced the source of contam-

TABLE 1

Borehole and well casing specifications

Borehole number	Augered depth (ft)	Length of casing (ft)	Inside diameter of casing (in)	Length of screen (ft)	Water table ^a depth below grade (ft)	Thickness of silica sand layer (ft)
BH-1	14.0	10.0	1.5	5.0	6.8	11.4
BH-2	14.0	10.0	1.5	5.0	7.1	11.9
BH-3	14.0	10.0	1.5	5.0	8.3	12.8
BH-4	14.0	10.0	1.5	5.0	9.0	11.6
BHI-1	12.0	10.0	1.0	2.5	6.4	6.9
BHI-2	14.0	10.0	1.0	2.5	6.6	8.5
BHI-3	13.1	10.0	1.0	5.0	6.8	10.1
BHI-4	13.0	10.0	1.5	5.0	6.7	10.1
BHI-5	15.0	10.0	1.5	5.0	6.5	12.3
BHI-6	13.0	10.0	1.5	5.0	6.3	10.4
BHI-7	14.5	10.0	1.5	1.5	6.0	7.9
BHI-8	14.2	10.0	1.5	1.5	6.3	11.0
BHI-9	13.5	15.0	1.5	5.0	6.0	5.5
BHI-10	7.3	10.0	1.5	5.0	6.1	4.7
BHI-11	15.0	15.0	1.5	5.0	N/M ^b	12.3
BHI-12	10.4	10.0	1.5	5.0	5.7	9.0
BHI-13	10.0	10.0	1.5	5.0	5.8	9.0
BHI-14	10.0	10.0	1.5	5.0	6.3	9.0
BHI-15	11.0	15.0	1.5	5.0	5.3	10.0

^aAll depths referred to finished floor slab level inside the building.

^bN/M denotes not measured.

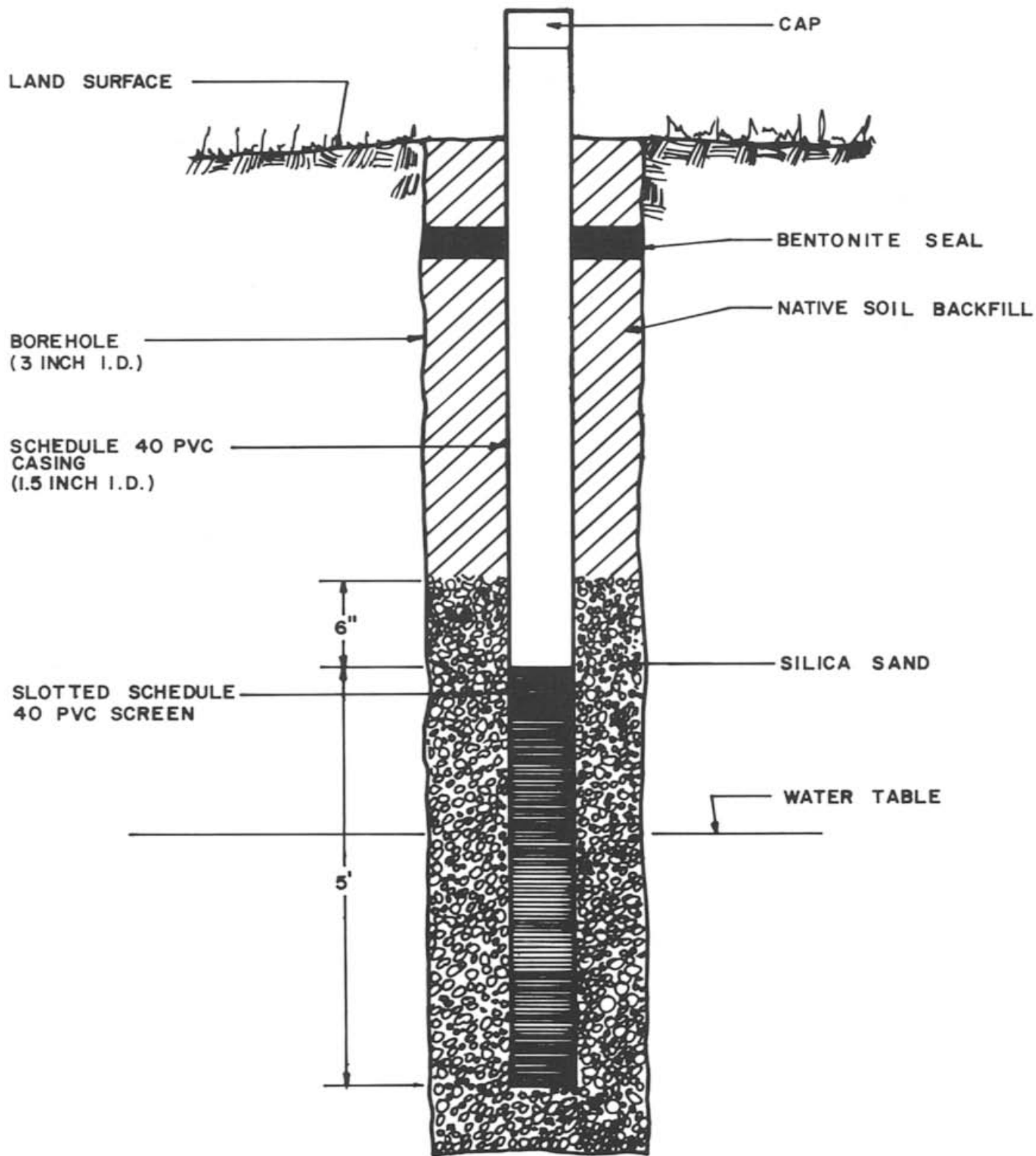


Fig. 2. Schematic of typical monitoring well.

ination to a leak in a neutralization pit measuring 20 feet long by 7 feet wide by 8 feet deep ($6 \times 2.1 \times 2.4$ m). The general orientation of the acid neutralization pits relative to the interior walls and column lines of the building is shown in Fig. 1.

A detailed borehole program consisting of nineteen monitoring wells was instituted to determine the vertical and lateral extent of contamination [4]. The borehole locations are also shown in Fig. 1. The extent of contamination was assessed by collecting soil samples from the boreholes at different depths, and water samples from the completed and developed wells. Fifteen boreholes

○ BH-4
8.9

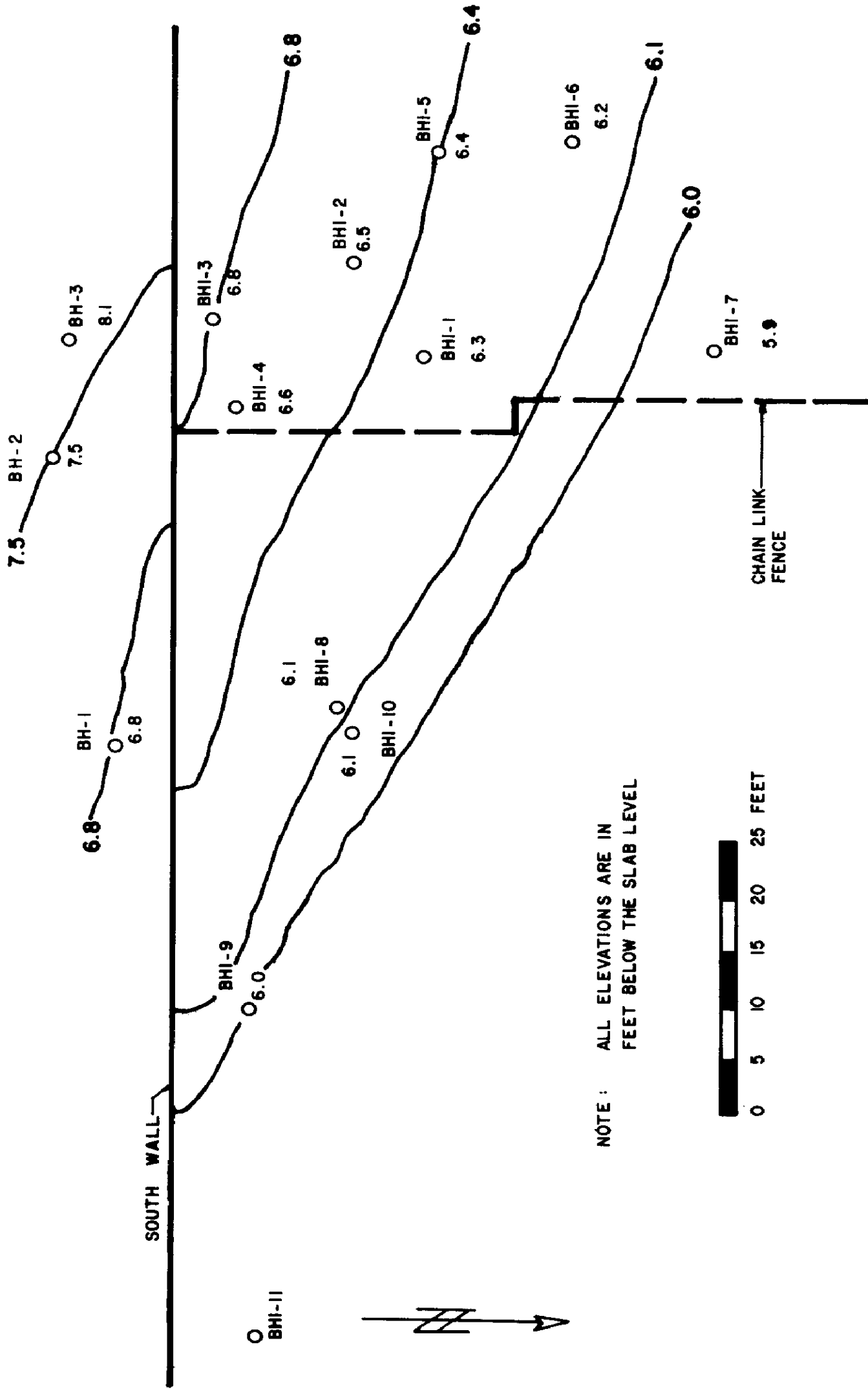


Fig. 3. Plot of water surface elevations.

were located inside the building and four boreholes were located outside the building.

Table 1 details the borehole and well casing specifications. The static water level in each well was measured with a float, as well as with a dip gauge. Several measurements of the levels were made until steady-state conditions were reached. Static water level measurements were recorded before field sampling of the groundwater. A schematic representation of a typical monitoring well installation is shown in Fig. 2.

A plot of the water surface elevation in the wells is shown in Fig. 3 and indicates that the groundwater flows in the southwesterly direction in the study area. All elevation shown in Fig. 3 are below the top of the concrete floor slab inside the building. All ground water contours have been interpolated from the measured water elevations.

Soil sampling

Soil samples were taken from the borehole cores at approximately 2-foot intervals. Variations in colour, odour, and soil type were recorded. All soil samples were stored in sealed glass containers and were kept in an ice bath to minimize loss of sample integrity. Standard sample handling precautions were taken to avoid cross-contamination.

Soil stratigraphy under the building

The upper 2 to 3 feet of each well consisted of a dry fill sand with some rubble, gravel, and traces of silt. This soil layer was dark brown and generally odour-free. The layer from 3 to 7 feet below the floor slab consisted primarily of a moist, fine grained, dense, brown sand with some traces of grey silt material. The plasticity and moisture content of the soil increased with depth in this region. Beyond a depth of 7 feet, the soil was generally a grey, well-compacted, silty clay till. At the 8.5-foot level within BHI-8 and BHI-9, shale fragments were encountered. The thickness of the zone containing shale fragments was approximately 1.5 feet.

Soil stratigraphy outside the building

The surface of the ground on the south side of the building consisted of a 6-inch layer of gravel intermixed with wood and steel debris. Ground cover in this area was mainly scattered weeds. Due to its permeable nature, this layer drained quickly and remained dry except for ponded water in localized depressions. Between 1 and 4 feet below the mean grade level, the soil was loosely compacted, wet, sand. This layer was free of organic odours. From 4 to 9 feet below grade, the degree of compactness and moisture content increased with depth. Traces of fine silt were encountered at depths of 9 to 11 feet. From 11 to 14 feet below grade, hard, grey, well compacted till was encountered. Traces

of till and fine-grained brown sand were intermixed in this layer. No shale fragments were encountered in any of the outside boreholes.

Water sampling

Water samples were collected from each borehole. All water sampling equipment was washed with tap water and distilled water before the next well was sampled. A stainless steel hand bailer was used to collect bulk water samples from wells for chromium analysis and to purge the well before sampling for organic contaminants. Bulk water samples were placed in 1-litre bottles. Water samples for organic analysis were collected in 25-ml bottles fitted with septums. No headspace was allowed in these sample containers.

Analysis

All soil and water samples were analyzed for pH, total chromium, hexavalent chromium, and trichloroethylene in accordance with the procedures recommended by the Ontario Ministry of the Environment (MOE) [5].

Examination of the field and laboratory data indicated that:

- the total chromium contamination penetrated to a depth of 15 feet (4.5 m),
- the TCE contamination penetrated to a depth of 13 feet (3.9 m),
- the projected floor area was approximately 3500 square feet (315 m²).

The south wall of the building acted as an effective barrier to the down-gradient transport of contaminants because the foundation and footings extended into the impermeable till layer. However, the weeping tiles surrounding the foundation of the electrical room provided a pathway for contaminated water to move from inside of the building to the outside.

All contaminated and uncontaminated groundwater entering the remediation area from the North was pumped out and treated as described in later sections of this paper.

The average concentrations of chromium and TCE over the borehole depths were calculated by dividing the entire area around the boreholes into polygons, as shown in Fig. 4. The polygons were formed by drawing lines perpendicular to those between adjoining boreholes. This standard method of dividing the floor area assumes that the contaminant concentration in each borehole is representative of a uniform distribution throughout the associated soil volume. This approach was dictated by the presence of operating equipment in most of the affected area.

The unit weight of the soil was estimated to be 165 lbf/ft³ (~ 2650 kg/m³) with a mean porosity of 25%. Consideration of the maximum observed concentrations provided the highest possible estimates for *in situ* chromium and TCE levels. Independent chemical analyses of the soil in the vadose and saturated zones and in the groundwater were used to estimate the maximum concentra-

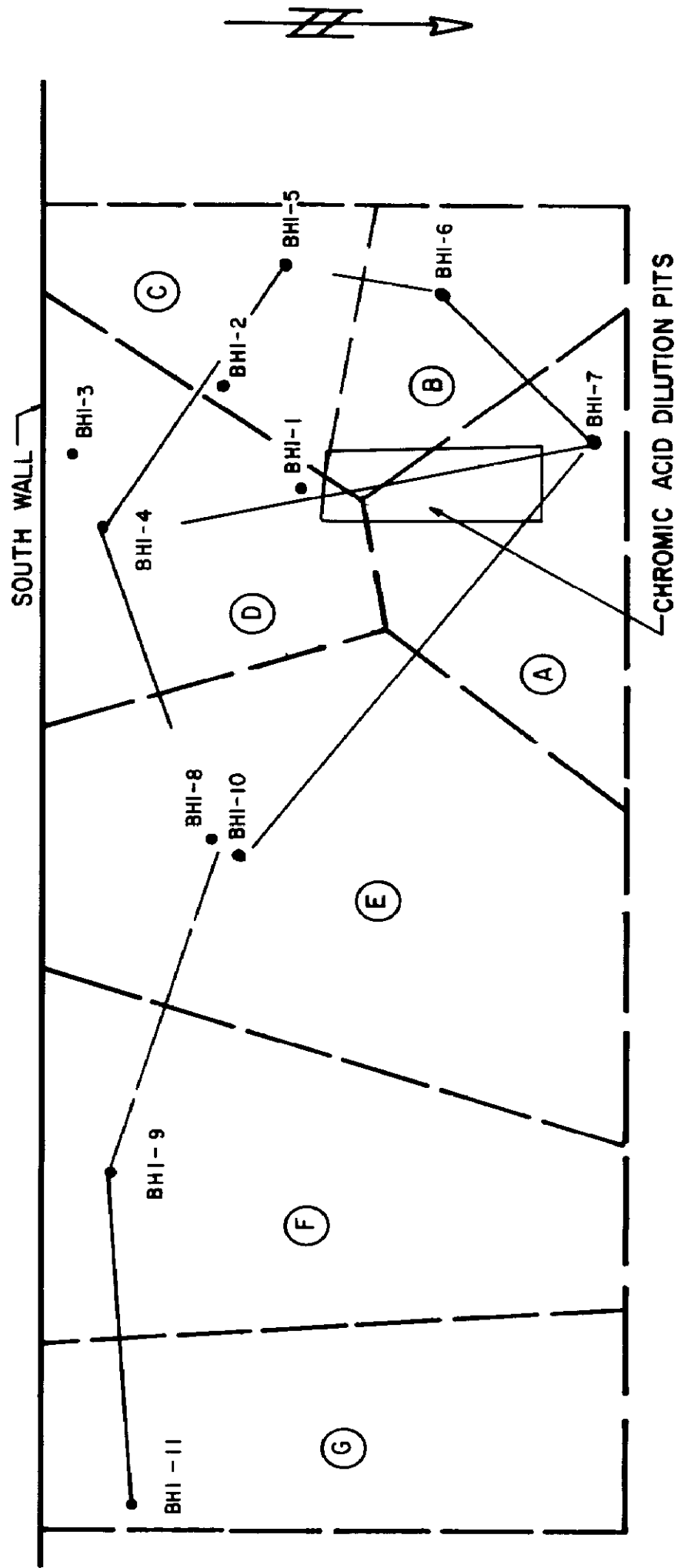
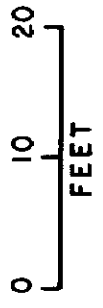


Fig. 4. Polygons used to estimate mass of contaminants.

tions of the contaminants associated with each borehole and polygon. The estimated masses of total chromium in the soil and water were 54 and 92 pounds, respectively. The maximum masses of TCE in the soil and water were calculated to be 88 and 17 pounds, respectively. At a groundwater temperature of 60°F (15.5°C), the TCE masses correspond to volumes of 6.0 and 1.1 gallons (22 and 4 l) respectively.

Remediation program

The selection of a suitable remediation technique depends upon the following factors:

- the extent to which the process removes the contamination,
- the extent to which the technique prevents the spread of the contamination in the downgradient direction,
- the degree to which the technique minimizes potential health risks to current and future occupants of the building,
- the economic feasibility of the technique,
- the technical requirements necessary to monitor the site, once the remediation technique has been employed.

To achieve the required objectives, a vertical/horizontal drainage system of purge pipes was designed as shown in Figs. 5 and 6.

The following hydrogeological conditions were taken into consideration:

- natural groundwater gradient = 0.018,
- hydraulic conductivity of sand = 3.3×10^{-5} ft/s,
- hydraulic conductivity of till = 7.5×10^{-8} ft/s,
- groundwater velocity in the saturated sand = 0.204 ft/day,
- groundwater velocity in the till = 0.012 ft/day (1.3 m/year).

The conductivities were measured in the field according to the piezometer test methods established by Hvorslev [6]. To facilitate the installation and operation of the purge system, a volume of 562 cubic yards ($\sim 395 \text{ m}^3$) of the most highly contaminated soil, covering a surface area of 1012 square feet to a depth of 15 feet, was removed from two locations. All necessary structural shoring was provided to ensure the stability of the roof and south wall of the building. The excavation was carried out in two stages to permit the installation of the purge pipes. During the first stage, purge pipes of 20 to 30 foot lengths were augered into the face of the excavation about 7 feet below grade and sloped at 2% toward the excavation. The purge pipes were 2-inch schedule 40, slotted PVC pipes with a geotextile filter cloth cover. To prevent the collapse of the boreholes, a steel outer casing was provided prior to installation of the PVC pipes. A bentonite seal of 1 foot length was used to secure the pipe at the facing of the excavation. Figure 6 provides a cross-section of a typical excavation and shows the associated purging equipment.

A 45-gallon drum was used as a “knock-out” tank during the suction of con-

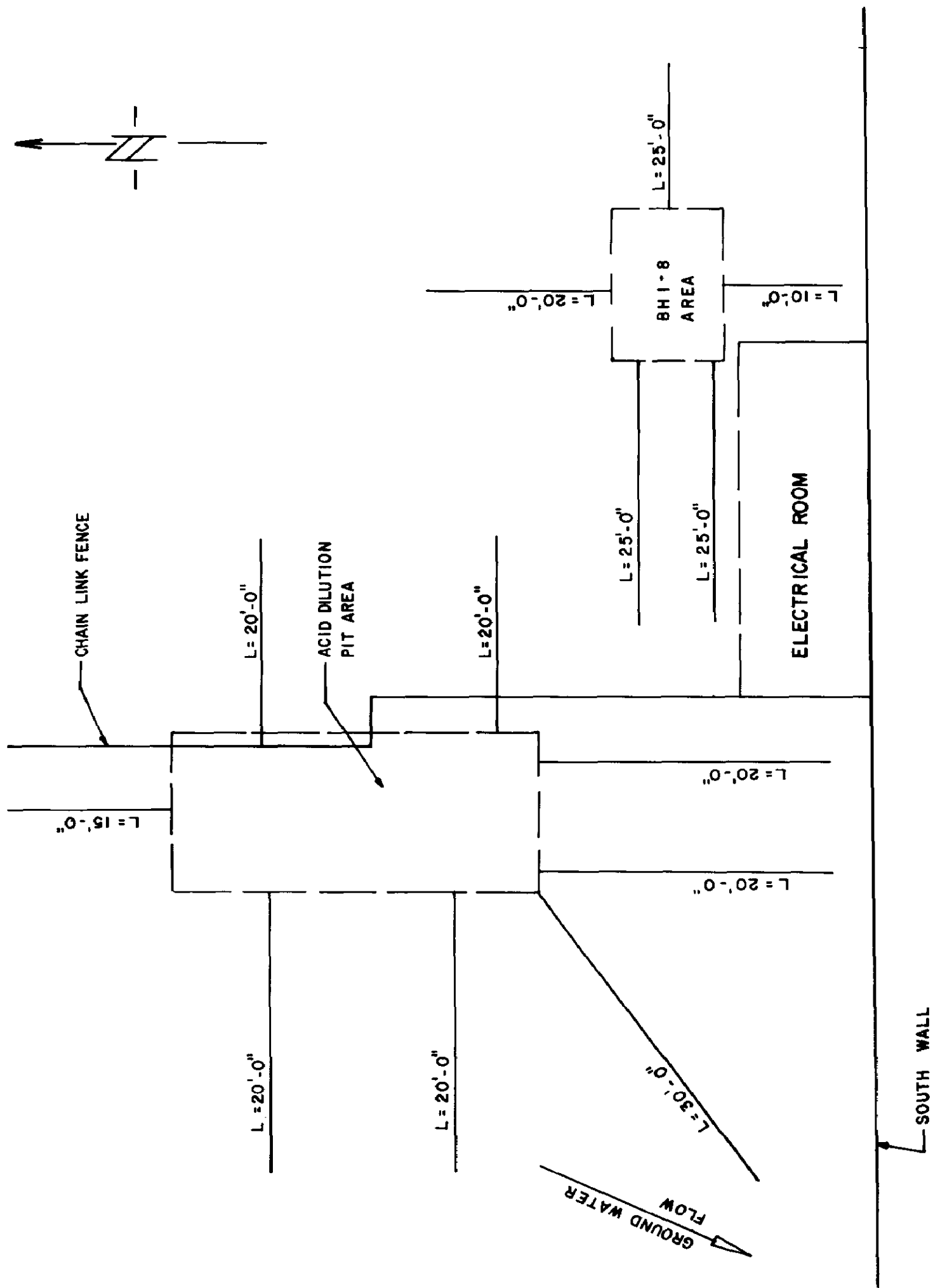


Fig. 5. Plan view of purge system.

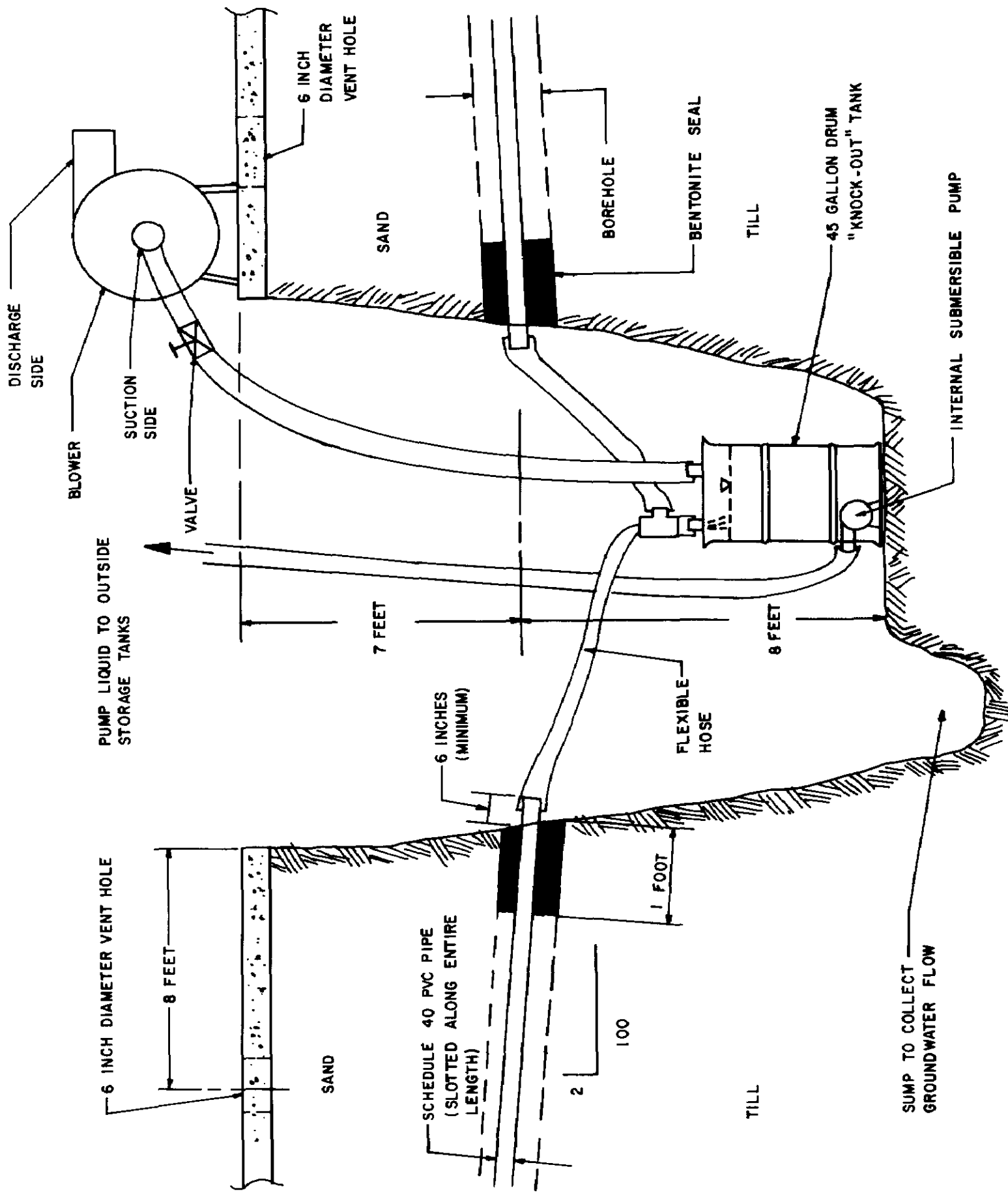


Fig. 6. Cross section of a typical elevation.

taminated groundwater by a 500 cfm (14 m³/min) blower. The applied suction of 25 inches of mercury significantly enhanced the rate of drainage of the groundwater.

Two 36-inch-square flooding ports were located above each purge pipe at floor level, at distances of approximately 8 and 15 feet from the face of the excavations. The movement of the groundwater was further enhanced by flooding at a rate of 5.5 gpm (~20 l/min) through each portal until the sand layer was completely saturated. This flooding significantly increased the local groundwater gradient. It was estimated that the drainage time with this additional flooding was reduced from 220 to 180 days by this additional flooding. The collected groundwater was stored in aboveground tanks for further treatment. The total volume of groundwater that was purged and treated was 26,400 gallons.

Analyses (chemical and physical) of purged groundwater and excavated soil provided data for the mass balance needed to determine the total mass of contaminants removed as a function of time. Based on the mass balance calculations, it was estimated that 96% of all chromium contamination and 98% of all TCE contamination were removed.

Groundwater treatment

The negotiated maximum allowable concentrations of TCE, total chromium and hexavalent chromium in the groundwater were 2.0 ppm, 5.0 ppm and 0.1 ppm.

During the first stage of the water treatment, the collected groundwater was treated for the removal of TCE. Air stripping of the TCE was carried out on-site, in a three stage, counter-current, packed-bed tower, designed and used by Clayton for similar groundwater remediation projects. The air stripper is a 17-foot high, 2-foot diameter column. The packed bed section is 10 feet long and contains 0.5 inch tripac packing materials. The air stripper was operated at a liquid flow rate of 6 gallons per minute. The air flow rate was 1000 cfm, to provide a liquid to gas ratio of 6 imperial gallons (~27 l) per 1000 cubic feet of air. This rate ensured the complete removal of TCE from the water.

During the second phase, the hexavalent chromium in the groundwater was reduced to trivalent chromium by:

- pH reduction to 2.5 with sulfuric acid,
- addition of sodium bisulphite to reduce the hexavalent to the trivalent state according to the chemical reaction [7]:

$$3\text{NaHSO}_3 + 2\text{H}_2\text{CrO}_4 \rightarrow \text{Cr}_2(\text{SO}_4)_3 + 2\text{H}_2\text{O} + 3\text{NaOH}$$
- increasing the pH to 7.0 by the addition of caustic soda which favoured the precipitation of the chromate sludge.

Prior to discharging the treated water to the municipal sanitary sewer system, residual levels of TCE and chromium were determined. In cases where

the TCE exceeded 0.01 ppm, the entire batch (2000 gallons) was re-processed through the air stripper. In all cases, the chromium reduction stage achieved the targeted residual chromium concentration of less than 1.0 ppm.

Soil treatment

The excavated soil was aerated naturally in 3-foot high piles to allow residual TCE to volatilize before disposal of the soil in an MOE approved landfill site. The soil piles were turned over daily to enhance TCE removal.

Cost evaluation

A comparison of the actual cost of the project, with the projected expenses of a traditional approach involving larger excavation and shoring requirement, indicates a total cost reduction of 40%; from US\$1.3 million to US\$780,000. Using the chemical data obtained from the analysis of soil and groundwater samples collected from the boreholes, it was estimated that removal of 1560 cubic yards of soil would have been required to achieve the specified cleanup level as opposed to the 562 cubic yards of material actually removed when the purge pipe scheme was operational. Both methods depended on maximum excavation depths of 15 feet. In addition, there was no interruption of essential services or production activities as a result of excavating under the electrical room. The electrical room supplying power to this facility was approximately 25 feet away from the original source pit.

The flooding, purging, and subsequent onsite treatment used in this project proved to be an economically viable approach for solving confined contamination problems.

Post remediation monitoring

The entire remediation was completed during the November, 1987 through May, 1988 period. To satisfy the regulatory requirements for verification of the cleanup, boreholes BH-3, BHI-4 and BHI-15 were converted to secured, long-term monitoring wells. Borehole BHI-15 was used to establish background, up-gradient, contaminations, whereas borehole BHI-3 was used to assess down-gradient residual contamination. The outside borehole, BH-4 was used to monitor for any residual contamination which could penetrate the south wall of the building and travel down-gradient and off the property. The property boundary is approximately 120 feet south of the wall of the building.

Table 2 illustrates the effectiveness of this remediation technique. Quarterly monitoring of groundwater samples has shown that residual TCE concentrations are less than 0.01 ppm and that residual chromium concentration are less than 2.0 ppm. Both contaminant concentrations are still decreasing with time.

TABLE 2

Variations in total chromium levels after the remediation work

Date	Concentrations of total chromium (ppm)	
	Borehole BHI-4	Borehole BH-3
October, 1988	4.3	<0.05
November, 1988	3.4	<0.005
January, 1989	3.5	<0.05
June, 1989	2.6	<0.05
July, 1989	2.4	<0.05

Conclusions

A combined horizontal/vertical purge pipe system was designed and implemented to remove chromium and trichloroethylene contamination from a sand aquifer confined beneath the floor slab of an industrial building. It was estimated that the system reduced remediation costs by 40% over a more traditional approach requiring a larger excavation. The majority of the cost savings was realized from not having to install extensive structural shoring to support the roof and columns of the building.

Organic and heavy-metal-contamination in the groundwater was removed by air-stripping and chemical precipitation. Heavy metal contaminated soil was disposed of in a hazardous waste landfill after on-site aeration. During the remediation, residual levels of chromium were reduced from 1060 ppm to less than 2 ppm and trichloroethylene residuals were reduced from 330 ppm to less than 0.01 ppm.

References

- 1 W.L. Crow, E.P. Anderson and E. Miniugh. Subsurface Venting of Hydrocarbon Vapors from an Underground Aquifer. American Petroleum Institute, Washington, D.C., p. 48.
- 2 D.L. Koltuniak. In-situ air stripping cleans contaminated soil, Chem. Eng., 93 (15) (1986) 30-31.
- 3 J.W. Noland, R.F. Weston and D.L. Koltuniak. Thermal stripping treatment of soils contaminated with volatile organic compounds, Proc. Air Pollut. Control Assoc. 80th Annual meeting. New York, NY, 1987, pp. 2-13.
- 4 U.S. EPA, Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities, Manual SW-611, U.S. EPA, 1977, pp. 269.
- 5 Ministry of the Environment, Handbook of Analytical Methods for Environmental Samples. Laboratory Services and Applied Branch, Rexdale, Ont., 1985.
- 6 M.J. Hvorslev, Time Lag and Soil Permeability in Groundwater Observations. U.S. Army Corps Engrs. Waterways Exp. Station, Bulletin 36, Vicksburg, MS, 1951.
- 7 M.R. Watson. Pollution Control in Metal Finishing. Noyes Data Corp., Park Ridge, NJ, 1973, pp. 294.