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TECHNICAL REPORT

Technical Impracticability Evaluation for the Rodale Manufacturing Site Emmaus, Pennsylvania

Square D Company
Palatine, Illinois

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BBL
BLASLAND, BOUCK & LEE, INC.
engineers & scientists

6723 Towpath Road, P.O. Box 66
Syracuse, New York, 13214-0066
(315) 446-9120

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1. Introduction

1.1 General

This draft Technical Impracticability (TI) Evaluation Report has been prepared by Blasland, Bouck & Lee, Inc. (BBL) on behalf of Square D Company/Schneider Electric (Square D) for the Rodale Manufacturing site located in Emmaus, Pennsylvania (Figure 1). This report augments the previous USEPA-approved Remedial Investigation (RI) (BBL, March 1998). Although this TI Evaluation has been formatted as a stand alone document for ease of review, it is submitted as a component of and in conjunction with the Draft Feasibility Study (FS) for the Rodale Manufacturing site.

This report has been prepared using data and information collected during the RI and previous investigations which were intended to support a "front-end" TI Evaluation (USEPA, September 1993; USEPA, January 1995) as part of the FS (BBL, July 1998). A front-end TI Evaluation of ground-water restoration for this site is considered appropriate based on the likely presence of dense non-aqueous phase liquid (DNAPL) deep in fractured bedrock at the site and the fact that dissolved constituents in ground water have diffused into the porous matrix of the fractured bedrock. The presence of known constraints to aquifer restoration, such as DNAPL, fractured bedrock, or other conditions, do not necessarily justify a waiver of applicable or relevant and appropriate requirements (ARARs), therefore, the USEPA-approved RI has gathered adequate site characterization data to demonstrate that, not only do particular constraints exists, but that the effect of these constraints on contaminant fate and transport, and the recovery of these contaminants within reasonable time frames poses a critical limitation to the effectiveness of proven remedial technologies. It should be noted that no proven technologies have been demonstrated for the remediation of DNAPL contamination in fractured bedrock (USEPA, September 1993).

1.1.1 Purpose for TI Evaluation

The purpose of this TI Evaluation is to assess the practicability from an engineering perspective of achieving ARARs with regard to restoration of ground water within a time frame that is reasonable given the circumstances of this particular site. The principle issues of concern in connection with this evaluation is the practicability of achieving relevant ground-water cleanup standards (i.e., maximum contaminant levels [MCLs]) for trichloroethene (TCE). The results of this evaluation will be used to support the United States Environmental Protection Agency (USEPA) in making a TI determination to approve a wavier of specific ARARs for which it would be technically impracticable to achieve.

1.2 Report Organization

The TI Evaluation components presented in this document are consistent with relevant guidance (USEPA, September 1993) and have also been organized in a manner consistent with this guidance. The introductory section of this document identifies the basis for implementing this TI Evaluation and establishes the purpose for the evaluation. Relevant background information pertaining to the site is presented in Section 2.0 of this document.

Section 3.0 identifies the site-specific ARARs for which a waiver is requested. A detailed discussion of the basis for establishing the spatial extent of the TI zone over which the TI decision would apply is presented in Section 4.0. Section 5.0 presents the current understanding of the site Conceptual Model components including the geology and hydrogeology of the site and vicinity, the nature and extent of volatile organic compounds (VOCs) in soil and ground-water, migration and exposure processes, and potential receptors. The restoration potential for the site is evaluated in Section 6.0. Cost Estimated costs for remedial alternatives is summarized in Section 7.0. Section 8.0 evaluates the protectiveness of the remedial alternatives. A summary and conclusions of the TI Evaluation are presented in Section 9.0. References made in the TI Evaluation are documented in Section 10.0.

2. Site Background

2.1 General

The site is located at Sixth and Minor Streets in the Borough of Emmaus, Lehigh County, Pennsylvania, about five miles south of the City of Allentown, as shown on Figure 1. The approximate site geographic coordinates are Latitude 40° 31' 53" N, Longitude 75° 29' 37"W. The site is bordered by Minor Street to the north, Sixth Street to the west, an alleyway to the east, and the Perkiomen railroad line to the south. Land use in the area surrounding the Rodale site includes residential as well as industrial and commercial facilities.

2.2 Site Background and History

The site property had been used for commercial or manufacturing purposes since at least the 1920s. Prior to the 1930s, the site was occupied by the D.G. Dery Silk Corporation and later by Amalgamated Silk Corporation. According to annual versions of the Pennsylvania Industrial Directory, Rodale Press, a publishing and printing business, occupied portions of the building from at least 1938 until 1959 (Pennsylvania Department of Health, 1991). From the late 1950s until 1975, the site was operated by Rodale Manufacturing to make wiring devices and electrical connectors. The manufacturing process included various electroplating techniques. In 1975, the site was sold to Bell Electric, a wholly-owned subsidiary of Square D, which manufactured similar electrical components. In 1986, Square D closed manufacturing operations at the site. Buildings at the site were partially demolished in 1989; the remaining portions were demolished in 1993. Previously-used waste disposal wells were identified during demolition activities.

Activities under Rodale Operation of Facility

Specific operational practices prior to 1961 are largely unknown. Pennsylvania Department of Environmental Protection (PADEP) files indicate that under Rodale Manufacturing's operation of the facility, several wells were used for disposal of various wastes. PADEP files indicated that in 1962, approximately 3,000 gallons per day (gpd) of wastewater, including rinse water from copper and zinc plating and acid brass dipping, were discharged to a 452-foot deep borehole (subsequently identified as Well 1) located in the former Courtyard Area (Figure 2). Borough of Emmaus files indicate that the electroplating room was connected to the sanitary sewer by January 1967. Rodale's operation continued until 1975 when the business was sold to Bell Electric (a subsidiary of Square D).

Activities under Square D Operation of Facility

Information regarding the past disposal practices at the site were first identified by Square D in March 1981, when a capped borehole (Well 1) was discovered during the installation of new equipment. Long-time employees of Rodale Manufacturing indicated that two other wells (Well 2 and Well 3) were also used for disposal purposes, and the locations of these wells were identified. From June to September 1981, Square D arranged for liquid wastes and some impacted ground water to be removed from Wells 1, 2, and 3, and disposed of by licensed haulers at licensed disposal facilities. A monitoring well (Well 4) was installed to a depth of 342 feet below ground surface (bgs) in June 1981 by Gill Enterprises on behalf of Square D. Water samples collected from the monitoring well and the three identified disposal wells revealed the presence of varying concentrations of VOCs, metals, and cyanide.

In addition to the three disposal wells (Wells 1, 2, and 3), two additional wells (Wells 5 and 6) were also identified by Square D at the site in the early 1980s. Well 5, a shallow cistern, was discovered in late 1981. Well 6, located at the west end of the Courtyard, was apparently used for makeup cooling water and not for disposal purposes.

In 1984, operation of an air-stripping tower commenced for removal of VOCs from ground-water pumped from Well 1. A National Pollutant Discharge Elimination System (NPDES) permit for surface discharge of treated ground water was issued by the PADEP. The pumping and air-stripping activities continued until 1989 when Square D proceeded with demolition of Building D and discontinued operation of the interim ground-water pumping and air stripping program. Ground-water monitoring results obtained between 1981 and 1988 indicated that the pumping and air-stripping activities were effective in lowering VOC concentrations in Well 1 from hundreds of parts per million (ppm) to less than 1 ppm (SNR Company [SNR], 1989).

Following closure of the facility by Square D in 1986, investigative and remedial activities continued. In 1988, Square D retained SNR of Laguna Hills, California to prepare a Ground Water Monitoring Plan. In preparation of this plan, SNR installed four ground-water monitoring wells (originally designated SW-A through SW-D and now referred to as MW-1 through MW-4) around the perimeter of the facility. The wells were screened near the water table. In 1989, the south wing (Building D) was demolished to provide space for additional remedial activities. During demolition, a well (designated WW-08, 6 feet in diameter and approximately 55 feet in depth) was discovered. Two fuel oil underground storage tanks (USTs) were also removed (Figure 2).

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Response Action and Subsequent Activities

In January 1989, NUS Corporation conducted a site Inspection (SI) on behalf of the USEPA at the site. The SI consisted of the collection of water samples from the three former on-site disposal wells, four on-site monitoring wells, three of the six Borough of Emmaus water supply wells, and three residential wells. In November 1989, the PADEP collected several water samples from wells located downgradient of the study area, including one Borough of Emmaus water supply well (PSW-7) and five downgradient private wells in Lower Macungie Township. A hydrogeologic investigation was completed by Roy F. Weston, Inc. (Weston) during 1989. In 1990, a monitoring/recovery well (RW-1) was installed at the site and another monitoring/recovery well (RW-2) was partially completed with the installation of surface casing. Final completion was to be based on the anticipated use of the well. The locations of all known disposal, production, recovery, and monitoring wells at the site are indicated on Figure 2. Table 1 presents summary information regarding well construction details, dates of installation, and a description of Wells 1 through 7, WW-08, RW-2, and for RW-3; while Table 2 presents a summary of the information regarding monitoring wells MW-1 through MW-4.

On July 29, 1991, following the Hazard Ranking System review process by the USEPA, the site was proposed for placement on the National Priorities List (NPL). An area of concern (AOC) to conduct the RI/FS was subsequently executed between the USEPA and Square D (effective September 21, 1992).

In 1993, Geo-Environmental Consultants, Inc. (GEC), a consultant to Square D, supervised the demolition of the remaining portion of the buildings. During demolition, two additional site features were identified:

- Well 7, which is believed to have been used for septic disposal; and
- Tank 1, which is a closed-bottom cistern possibly used for fuel oil storage.

The locations of both features are illustrated on Figure 2.

GEC implemented two additional phases of investigation, which were reported in the Well Survey Evaluation Report (GEC, September 1994) and the Time-Critical Investigation Report (GEC, October 1995).

A separate AOC for Removal Response Action (RRA) (USEPA Docket No. 111-94-15-DC) for a site ground-water treatment system (GWTS) and related tasks was also executed between the USEPA and Square D, effective September 30, 1994.. The document entitled "Supplement I to the Time-Critical Work Plan for the Rodale Manufacturing site," which includes a conceptual design for the ground-water pump-and-treat system was prepared and submitted to the USEPA (GEC, February 28, 1995) pursuant to this AOC. Supplement I also included a presentation of site conditions, an evaluation and screening of treatment technologies, and the conceptual design of the subsequently constructed ground-water pump-and-treat system.

2.3 Physical Setting of the Site

2.3.1 Topography and Ground Cover

Topography in the Borough of Emmaus varies from between 350 feet and 500 feet above mean sea level (AMSL) (USGS, 1992). The most prominent topographic feature in the vicinity of the site is South Mountain to the south and southeast with gently sloping hills and stream valleys to the west, north, and northwest. The peaks of South Mountain extend as high as 1,000 feet AMSL. Topographic features in the vicinity of the site include: the Lehigh River; Leibert, Little Lehigh, Swabia, and Cedar Creeks; Chestnut Hill; Lock Ridge; and Bauer Rock. Elevations across the 1.2-acre site range from 460 to 470 feet AMSL, with the lowest point located within the central portion of the northern half of the site.

Given the observed site topography and the fact that the entire site surface is covered with crushed stone, most of the precipitation to the site would be expected to infiltrate into the subsurface during most rain events, and no significant runoff would be anticipated from the site. Any surface water runoff which may occur from this site would be discharged by the storm sewer system into the Unnamed Tributary approximately 2,500 feet west of the site.

2.3.2 Geology

The area of the site is characterized by the crystalline rocks comprising South Mountain to the east and south of the site, and the Cambrian and Ordovician sedimentary units of the Little Lehigh Creek basin extending north and west of South Mountain (Figure 3). Due to the complex geologic nature of the region, the following discussion of the region's geology and hydrogeology is focused on that portion of the region and those geologic units which can affect or be affected by ground-water flow through and downgradient of the site.

Stratigraphy of the Little Lehigh Creek Basin

Precambrian-Aged Crystalline Rocks of the Reading Prong

The oldest rocks of the Little Lehigh Creek basin are the Precambrian-aged crystalline rocks of the Reading Prong, which are structurally complex and are composed of undifferentiated granitic gneiss, hornblend gneiss, and other gneisses and pegmatites (Sloto, et. al., 1991). These rocks and the Cambrian-aged Hardyston Quartzite (discussed below) comprise South Mountain. The Reading Prong (including South Mountain) rock units strike northeast-southwest in the area west and south of the Rodale site dip toward the northwest, and define the southern margin of the Little Lehigh Creek basin.

Hardyston Quartzite

The Lower Cambrian Hardyston Quartzite comprises the youngest lithologic unit of the Reading Prong. This unit consists of a light gray, medium- to thick-bedded quartzite and feldspathic sandstone with a basal quartz-pebble conglomerate (Wood, et. al., 1972; Sloto, et. al., 1991). The Hardyston Quartzite unconformably overlies the Precambrian crystalline rocks of the Reading Prong and ranges in thickness from 100 to more than 800 feet (Sloto, et. al., 1991).

Leithsville Formation

The Middle and Lower Cambrian Leithsville Formation is the oldest of the Paleozoic carbonate rocks in the Lehigh Valley. This unit is composed predominantly of gray to yellowish, thin bedded dolomites that grade locally into sericitic shales, with some massive beds of blue dolomite (Wood, et. al., 1972). Nearly all of the Leithsville Formation in Lehigh County occurs on, or near, the western flank of South Mountain (Wood, et. al., 1972). The

Leithsville Formation is approximately 400 feet thick and is sometimes conformable but most commonly in faul contact with the underlying Hardyston Quartzite (Sloto, et. al., 1991). The unit has a strike of northeast-southwest, and a northwestward dip, paralleling South Mountain in a band approximately one-half mile to one mile wide (Kochanov, 1989). The site is situated directly over the subcrop of the Leithsville Formation.

Allentown Dolomite

Within the Little Lehigh Creek Basin the Allentown Dolomite (Upper Cambrian and Lower Ordovician) is the next oldest lithologic unit and conformably overlies the Leithsville Formation. The Allentown Dolomite bedding is parallel to the Leithsville Formation and South Mountain, and its subcrop width ranges between approximately 2 and 4 miles. The lithology of the Allentown Dolomite formation is a light- to dark-medium gray, very fine- to medium-grained, rhythmically bedded dolomite containing abundant algal stromatalites and beds and lenses of orthoquartzite. The Allentown Dolomite is approximately 2,500 feet thick (Sloto, et. al., 1991).

Overburden Material

Deep sections of weathered carbonate residual (e.g., saprolite) deposits occur above the competent bedrock of the carbonate units of Little Lehigh Creek basin, overlain in some areas by glacial drift deposits, and generally capped with a soil loam horizon. The saprolite material represents in-place, chemically-weathered bedrock and reportedly ranges in thickness from zero to approximately 150 feet throughout the region, with an average of approximately 65 feet thick (Wood, et. al., 1972). Illinoian (Quaternary) terminal moraine glacial deposits overlie portions of the saprolite of the Leithsville Formation and Allentown Dolomite. These deposits are reportedly thin where present, approximately 6 to 8 feet thick in the area north of Community Park in Emmaus (SNR, March 1989). Soils of the Merrill gravelly loam, the Washington silt loam, the Duffield silt loam, and the Bedford silt loam reportedly occur above these units in the site vicinity. Loam deposits average approximately 4 feet in thickness (Wood, et. al., 1972).

Based on a detailed mapping of the surficial geology of the Allentown East 7.5-minute Quadrangle (Braun, 1996), the site lies within a region defined as a Urban Land soil classification. To earn this designation, the surface soil had to have been cut and filled disturbing more than 50 percent of the area (soil), and includes most areas with homes on one-half acre or smaller lots, commercial sites, and industrial sites.

Approximately 300 feet to the south of the site lies the northern extent of a lobe of Colluvium (soil) derived from limestone and sandstone. This soil is a sparsely stony, matrix-supported diamict, and its matrix is a yellowish-brown clay to silt. Within this soil, angular to subangular clasts of sandstone, granitic gneiss, limestone, dolostone and chert in sizes ranging from cobble to boulder-sized, exhibiting a strong downslope orientation or forming crudely layered lenses. These deposits typically range in thickness from 6.6 to 20 feet (Braun, 1996).

Approximately 200 feet to the north of the site lies a south lobe of Pre-Illinoian Outwash. This overburden material contains a matrix-supported, yellowish-red roundstone "diamict" 3 to 9 feet thick. It is only observed in the Emmaus and Emmaus Junction area of the Allentown East 7.5-minute Quadrangle. It is underlain in some places by reddish yellow, stratified silt, sand, and pebble to cobble gravel, with some boulders. The pebbles and cobbles are well-rounded with weathering rinds up to 0.4 inches thick on quartz sandstone clasts, weaker clasts weathered throughout; smooth-sloping to relatively flat surfaces. The maximum thickness of this overburden is about 98 feet thick (Braun, 1996).

Structural Geology of the Little Lehigh Creek Basin

Drake (1978; 1987) described the regional structural geology as a series of large overturned folds and major thrust slices due to repeated episodes of faulting and folding during the Taconic (Late Ordovician) and Allegheny (Late Permian) Orogenies. Regionally, the strike of structures and geologic units is generally northeast-southwest, with the exception of localized features due to multiple deformations, high-angle faults, and antiformal or sysformal attitudes. Most of the bedding and associated bedding plane fractures dip toward the northwest. Some folded beds, thrust faults, and thrust slices also dip to the south or southeast (Sloto, et. al., 1991). SNR (1989) estimated the average regional strike and dip for the carbonate rocks at North 65 degrees East, 35 to 65 degrees northwest, using the three point method and the depositional contact between the Leithsville Formation and the Allentown Dolomite.

Abundant evidence and literature describes the area as extensively faulted. Wood, et. al. (1972) describe the thick sequence of extensively fractured and weathered Cambrian to Ordovician Age carbonate rock in the area. Sloto, et. al. (1991) present a geologic map illustrating the positions of several high-angle fault contacts within a one-mile distance east and south of the site, generally trending parallel and perpendicular to the strike of South Mountain. Faults also commonly separate geologic units in the Lehigh Valley. Relevant portions of the Wood, et. al. (1972) and Sloto, et. al. (1991) maps are illustrated on Figures 3 and 4, respectively. These figures are provided to illustrate relevant information regarding the regional geologic setting. While these figures are not in complete agreement, both offer very similar interpretations of the locations of lithologic contacts and major structural features. SNR (1989) discusses the considerable faulting, folding, and fracturing of the carbonate rocks in the site vicinity, and reported that the Leithsville Formation has a large number of joints and fractures. Weston (1989) modified an earlier fracture trace study of the area by R.E. Wright Associates (1982) and identified two general sets of dominant fracture traces. The primary set has an apparent strike of approximately east-west, and the secondary set has an apparent strike of approximately north-south, which are related to joint sets perpendicular and parallel to bedding. Additionally, an east-west primary fracture trace was interpreted as projecting through the site (R.E. Wright Associates, 1982). However, none of the borings conducted as part of the RI or previous investigations are known to have intercepted this fracture trace.

2.3.3 Hydrogeology

Ground-water flow within the Little Lehigh Creek Basin is generally from the areas of high elevation defining the valley's margin towards Little Lehigh Creek. South of Little Lehigh Creek, ground-water flow is from the crystalline rocks of the Reading Prong (South Mountain), defining topographic and ground-water divides along the southern margin of the Little Lehigh Creek Valley, to the northwest beneath the site and towards Little Lehigh Creek. This general direction of ground-water flow is approximately perpendicular to the strike of South Mountain. Ground water within the Little Lehigh Creek Basin discharges to Little Lehigh Creek, which eventually discharges to the Lehigh River. Ground-water discharge is the main source of water for Lehigh Creek (Wood, et. al., 1972).

The soil and saprolite materials forming the overburden materials in the site vicinity are very permeable and account for the transmission of the majority of local precipitation to the ground-water system of the carbonate rocks, as opposed to direct surface runoff (Wood, et. al., 1972).

Ground-water flow through the "highly-deformed" carbonate bedrock of the valley floor along the flow path from the topographic highs to the Little Lehigh Creek most likely follows a circuitous route through the solution-enhanced fractures of the carbonate bedrock. Due to similarities in composition, as well as structural history and resultant faulting episodes, the Leithsville Formation and the Allentown Dolomite are essentially considered as a single hydrogeologic unit (Wood, et. al., 1972; Sloto, et. al., 1991). The Leithsville Formation and the Allentown Dolomite are carbonate rocks which are susceptible to solution enlargement of secondary openings (i.e., along bedding planes, fracture planes, and joints). Solutioning is evident in these units by the observed presence of karstic features such as sinkholes (which develop over subsurface solution cavities and are prevalent in the Allentown Dolomite and rare in the Leithsville Formation), which typically develop at intersections of secondary openings (Sloto, et. al., 1991). Ground-water flow in these carbonate units is primarily along secondary openings. A ground-water flow gradient has been calculated as approximately 27 feet per mile from the base of South Mountain to Little Lehigh Creek, utilizing regional ground-water study data (Wood, et. al., 1972). Both confined and unconfined ground-water conditions are present in the Leithsville Formation and the Allentown Dolomite.

Each of the bedrock units in the Little Lehigh Creek Valley is a good ground-water producer due to the extensive joints and fractures present and, in the case of the carbonates, the solution enhancement of these secondary openings. Bedrock ground water provides the Borough of Emmaus and the Little Lehigh Creek basin with approximately 60 percent of its potable water supply (Wood, et. al., 1972). The permeable nature of the overlying soil and the weathered bedrock (saprolite) horizon above competent bedrock allows the majority of precipitation above the carbonate units to recharge the ground-water system and not directly discharge via surface-water routes. The Leithsville Formation and the Allentown Dolomite are locally the most important water-bearing units. Four of the six public water supply wells for the Borough of Emmaus are completed in the Leithsville Formation (PSW-1, PSW-2, PSW-3, and PSW-4). These wells range in depth from 183 feet to 526 feet, and range in yield approximately 123,000 to 244,000 gpd each. One public supply well (PSW- 7) was installed within the Allentown Dolomite. This well was completed to a depth of approximately 400 feet and provided a daily yield of approximately 119,000 gallons. The remaining public supply well (PSW-6) was completed within the Hardyston Quartzite, yielding approximately 460,000 gpd at a total depth of 358 feet (Wood, et. al., 1972). The crystalline rocks of the Reading Prong also can be a source of water for domestic use, especially along the slope of South Mountain where fractures are prevalent.

2.4 Types and General Distribution of Chemicals of Concern

An evaluation of the nature and extent of contamination was made for all environmental media at the site as part of the RI or previous investigations. A summary of the findings is presented below:

- Subsurface soil sampling results (Figure 5) indicate the presence of TCE and other constituents at concentrations above PA Interim Cleanup Standards and/or the PA Act 2 Standards within a limited area adjacent to one of the wells used for waste disposal. Of the 16 VOC exceedances observed, 14 of these exceedances occurred between the depths of 40 feet and 90 feet within soil borings which are situated in the immediate vicinity of former Injection/Disposal Well 2. These results demonstrate that the extent of impacts to the subsurface soil are limited to small area within the center of the site. Furthermore, an evaluation of the potential contribution from leaching of VOCs from this soil using the VLEACH model has demonstrated that the mass of VOCs associated with this potential contribution is negligible in comparison to the continuing source represented by the volume of DNAPL estimated to exist within the fractured bedrock beneath the site (BBL, July 1998).

- Dissolved TCE concentrations in ground-water samples collected during the RI were observed to exceed 1 percent of TCE's single-component solubility (1 percent of 1,100,000 micrograms per liter [µg/L] = 11,000 µg/L) in six of the on-site wells (Figure 6) including RW-3 (490,000 µg/L), Well 2 (420,000 µg/L), Well 4 (140,000 µg/L), Well 3 (100,000 µg/L), MW-4 (45,000 µg/L), and MW-1 (17,000 µg/L). These dissolved TCE concentrations are indicative of the presence of DNAPL in the immediate vicinity of these wells.

- Analytical results of ground-water samples collected during July 1998 to assess changes in ground-water quality in response to the initial operation of the GWTS are summarized in Tables 3 through 6. The supplemental sampling event documented concentrations of dissolved TCE which continue to exceed 1 percent of TCE's single component solubility in four wells within the probable DNAPL zone, including RW-3 (180,000 µg/L), Well 2 (330,000 µg/L), Well 4 (41,000 µg/L), and MW-4 (60,000 µg/L). These observed concentrations indicate the presence of DNAPL.

- Dissolved TCE concentrations observed in the ground-water samples from the off-site monitoring wells (Figure 7) were all at or below the USEPA maximum concentration limit (MCL) of 5 µg/L, with the exception of the samples from the shallow and deep wells at the MW-9 cluster, which contained 22 µg/L and 1,000 µg/L, respectively. However, the dissolved constituents observed in the monitoring wells at the MW-9 monitoring well cluster do not appear to be related to the site given the fact that the hydraulic head in these wells has been observed to be consistently higher than the hydraulic head at the site. A separate source of VOCs in ground water unrelated to the site is evident based on this observation.

- The results of the off-site ground-water sampling of private wells performed in connection with the Well Survey Evaluation (GEC, 1993), identified only two samples (PW-LM20 and PW-SA08Dup) and one spring sample (SP-03) in which any VOCs were observed above relevant regulatory criteria. However, trace concentrations of VOCs were detected in numerous private wells located upgradient or side gradient from the site. This further supports the existence of other sources (unrelated to the site) of dissolved constituents to ground water in this vicinity.

Ground-Water VOC Plume

The most frequently detected contaminants in ground water are: TCE; 1,2-dichloroethene (1,2-DCE); vinyl chloride (VC); tetrachloroethene (PCE); 1,1,2-trichloroethane (1,1,2-TCA); and 1,1-dichloroethene (1,1-DCE). TCE is the most widespread VOC found at the Rodale site, and therefore is considered representative of the maximum extent of contamination. To more clearly illustrate the distribution and limited horizontal extent of TCE in ground water, an isoconcentration map is shown presented on Figure 8. Although dissolved TCE concentrations at the site have been observed to range up to 570,000 µg/L, dissolved TCE concentrations in ground water have also been observed to decline below 5 µg/L within less than 700 feet downgradient of the site. This figure also illustrates the separate plume of dissolved constituents observed in the vicinity of the monitoring well MW-9 cluster which is unrelated to the site. It should be noted that the hydraulic influence associated with the operation of the ground-water treatment system at the site has been observed to be limited to an area within a few hundred feet of the site boundaries and does not have a measurable effect upon the hydraulic heads at the MW-9 cluster.

Although VOCs were widely detected in ground water on-site, evidence exists that suggests that natural attenuation is occurring [BBL, March 1998]. This conclusion is supported by the site ground-water analytical data, which demonstrate that a population of microorganisms is present in ground water at the site capable of utilizing anthropogenic carbon as a food source, a variety of complete redox processes is occurring in ground water at the site, and dechlorination byproducts of VOCs in ground water are abundant.

3. Site-Specific ARARs for Which Waiver is Requested

Under certain circumstances, a remedial alternative that does not meet an ARAR may be selected, and a waiver of the necessity to comply with the ARAR may be granted. Of the six sets of circumstances described in Section 300.430(f)(1)(ii)(c) of the National Contingency Plan (NCP) (40 CFR Part 300) for which waivers may be granted, one is considered applicable to the Rodale site:

> "Compliance with the requirements is technically impracticable from an engineering perspective."

ARARs potentially applicable to this site include the Safe Drinking Water Act (SDWA) MCL for TCE which is designed to require restoration of ground water to drinking water quality levels. However, it has been documented that DNAPL is present in ground water at the site [BBL, 1998]. According to the document, "Estimating Potential for Occurrence of DNAPL at Superfund sites: "Although many DNAPL removal strategies are currently being tested, to date there have been no field demonstrations where sufficient DNAPL has been successfully recovered from the subsurface to return the aquifer to drinking water quality" (USEPA, 1992). Furthermore, it has been published that "most of the sites where EPA already has determined that ground-water restoration is technically impracticable have DNAPL present [USEPA, 1993, p. 2]. As a result, it may be necessary to invoke a waiver under CERCLA Section 121 (d)(4) of those related to aquifer restoration.

Therefore, this Technical Impracticability Evaluation Report has been prepared to support a decision by the USEPA to approve a waiver of the Safe Drinking Water Act (SDWA) MCL for TCE with regard to the portion of the aquifer demonstrated to contain DNAPL.

It is understood that the request for a TI waiver will be evaluated in consideration of the USEPA's "Guidance for Evaluating the Technical Impracticability of Groundwater Restoration" (USEPA, September 1993).

Although a TI wavier is requested only for the ARAR pertaining specifically to TCE (the demonstrated DNAPL constituent), implementing active remedial measures to achieve ARARs pertaining to other constituents of concern within the Probable DNAPL Zone would not add additional benefit given the technical impracticability of achieving the ARAR pertaining to TCE. Similarly, active remedial measures to address the limited area of soil contamination above the TI Zone would have no additional benefit as the contribution of dissolved constituents to ground water associated with these contaminated soil are negligible in comparison to contributions from the DNAPL within the TI Zone.

4. Spatial Extent of TI Zone

Establishing an appropriate spatial extent of the TI Zone for this site focuses on delineating the Probable DNAPL Zone. Delineation of the Probable DNAPL Zone is important because USEPA recognizes that restoration of ground water is technically impracticable at sites where DNAPL is present, particularly in fractured bedrock, and USEPA has stated that ARAR waivers will generally be appropriate for these sites (USEPA, 1995).

Ground-water data have been used to delineate the Probable DNAPL Zone by identifying wells that indicate the likely presence of proximal DNAPL based on ground-water VOC concentrations exceeding 1 percent of the solubility of TCE in ground water (USEPA, 1992; Cohen and Mercer, 1993).

The estimated boundaries of the Probable DNAPL Zone were also based on knowledge of the site history and site usage as well as the distribution of locations where DNAPL was directly observed based on either visual determination (direct visual identification) or chemical confirmation via laboratory analysis.

The estimated horizontal and vertical extent of the Probable DNAPL Zone is illustrated on Figures 9, 14B and 15B. This estimate of the Probable DNAPL Zone extent was delineated largely based on an approach presented in USEPA guidance on DNAPL site evaluation (USEPA, 1992) and other sources (Cohen and Mercer, 1993; WCGR, 1991; Pankow and Cherry, 1996). DNAPL presence is strongly suggested and can reasonably be expected to occur in immediate proximity to any monitoring well exhibiting VOC concentrations greater than 1 percent of the VOC effective solubility limit (WCGR, 1991; USEPA, 1992; Cohen and Mercer, 1993; Pankow and Cherry, 1996). It should be noted that dissolved concentrations of DNAPL constituents detected in ground-water samples collected in close proximity to DNAPL may be below the constituent solubility limits due to several factors, including:

- Reduced effective solubilities due to multi-component DNAPL;
- Heterogeneous distribution of the DNAPL as residuals, pools, or layers;
- Hydrodynamic dispersion (including diffusion) within the geologic medium; and
- Dilution in wells with long intake sections (Pankow and Cherry, 1996).

5. Site Conceptual Model

5.1 Source of Dissolved VOCs and DNAPL

The source of the dissolved VOCs and DNAPL observed in the ground water beneath this site has been identified as the discharge of industrial waste water associated with the operation at the Rodale Manufacturing Facility into several deep disposal wells on the site. These disposal wells served as the only known waste water disposal method until the facility was connected to the sanitary sewer in 1967. Although little documentation exists regarding the nature of the wastes discharged into the on-site disposal wells throughout the operating life of this facility, these wastes would have included plating wastes and waste solvents.

The identification of the on-site disposal wells as the source of the dissolved VOCs and dense non-aqueous phase liquids (DNAPLs) is further supported by the analytical results of the samples collected to evaluated subsurface soil conditions at this site. These soil data clearly demonstrate the presence of VOC concentration indicative of DNAPL in the subsurface soil adjacent to disposal Well 2 at a depth which corresponds to the level at which waste water discharged into this wells could have entered the subsurface through breaks in the disposal wells casing.

5.2 Site Geology and Hydrogeology

The site geology and hydrogeology information presented in this component of the site conceptual model has been developed based on the results of the RI as well as previous investigations.

Field observations during the advancement of boreholes drilled during the RI confirmed that the first bedrock unit encountered in the immediate site vicinity consists of carbonate rocks of the Leithsville Formation locally composed predominantly of gray to yellowish buff, fine-grained, thin bedded dolomites that grade locally into massive beds of blue gray dolomite. Bedrock units were also observed to be interbedded with various thicknesses of calcareous shale. The Leithsville Formation is approximately 400 feet thick and is sometimes conformable but most commonly in fault contact with the underlying Hardyston Quartzite (Sloto, et. al., 1991). This contact with the Hardyston appears to have been encountered at a depth of approximately 291 feet below ground surface (bgs) in the borehole for monitoring well MW-5D. Subcrops of both the units trend northeast to southwest paralleling South Mountain in a band approximately one-half mile to one mile in width (Kochanov, 1989). Deep sections of weathered carbonate residual deposits (saprolite) occur above the competent bedrock of the carbonate units of Little Lehigh Creek basin, overlain in some areas in the vicinity of the site by glacial drift deposits, and generally capped with a soil loam horizon. The saprolite material represents in-place, chemically-weathered bedrock reported to range in thickness from zero to approximately 150 feet throughout the region, although averaging approximately 65 feet in thickness (Wood, et. al., 1972). Observations from the boreholes completed in connection with the RI indicate the saprolite may contain sericitic shales and varies in thickness from approximately 50 feet to more than 250 feet in the site vicinity.

To illustrate the nature and relative thicknesses of the overburden, saprolite and competent bedrock units forming the subsurface in the site vicinity, five detailed geologic cross sections (A-A', B-B', C-C', D-D', and E-E') were developed based on the known subsurface data and are presented on Figures 11 through 15. The locations of these geologic cross sections are identified on Figure 10. The information presented on these geologic cross sections includes lithologic descriptions of the geologic units encountered at each borehole location and potentiometric contours based on the January 7, 1997 measurements. Information regarding the frequency of fractures encountered during borehole advancement are also posted to these geologic cross sections. The intervals monitored by each of the wells located along the cross sections are also identified. The lithologic information presented on these cross sections illustrates the high degree of variability observed in the Leithsville Formation in the site vicinity, both horizontally and vertically. The information regarding frequency of observed fractures/broken zones suggests the bedrock is highly fractured in the site vicinity. While boreholes typically contained some segments up to 20 feet in length, over which no significant fractures were observed, the majority of the bedrock penetrated by these boreholes was observed to have a much higher fracture frequency. It is clear from these geologic cross sections that the depth of the overburden materials and the thickness of the saprolite vary substantially across the site vicinity.

Surface elevation contour maps for the weathered bedrock and the competent bedrock surfaces are presented on Figures 16 and 17, respectively. These figures suggest the presence of depressions in the bedrock surface which appear to extend from the an area immediately to the west of the site generally toward the northwest, suggesting the presence of paleochannels incised into the rock. These paleochannels are probably related to bedrock structure.

Observations of the continuous bedrock core obtained during advancement of the deep borehole at the monitoring well MW-10D location are documented on its boring log. High frequencies of fractures and joints were observed intersecting the borehole along a majority of its depth. Multiple high angle fractures and/or joints intersect, resulting in broken zones typically 1 to 2 feet thick, were observed at various depths. Quartz and calcite mineralization within joints and microfractures were also frequently observed throughout the bedrock sequence at the MW-10D location.

Geologic cross sections presented on Figures 11 through 15 include lithologic descriptions and structural observations made during the subsurface investigations, in and indicated in the subsurface boring logs presented as Appendix E of the RI Report. As noted on these logs, some of the descriptions were based upon indirect observations during drilling such as penetration speed and examination of cuttings. Intervals of highly fractured or weathered zones have been noted on the cross sections. These highly fractured or weathered zones appear either as a continuous, relatively long, generalized intervals or as smaller, discrete intervals (black zones on figure), moreover, these highly fractured or weathered zones are interpreted as zones of relatively high secondary porosity. The corresponding elevations for these zones are enumerated in the following table.

Well/Boring	Elevation Intervals of Higher Secondary Porosity (ft. AMSL)	Bottom Elevation (ft. AMSL)
MW-5D	231 to 218.5, 182 to 172.5	135
MW-6D	400 to 395, 373 to 371, 367.5 to 365, 326 to 324, 320 to 315	315
MW-8D	325 to 315, 299 to 272, 260 to 255	240
MW-9D	387 to 385, 382 to 381, 380 to 379, 372 to 371, 336 to 337, 325 to 321, 320 to 319,311 to 310, 283 to 282.8, 282 to 281.8, 271 to 270, 268 to 267, 261.5 to 261, 246 to 244, 242 to 240.5, 239.5 to 238, 230 to 229, 224 to 222, 207 to 205, 203 to 201, 195, 188 to 187.5, 184 to 183.5, 178.5 to 178, 177.5 to 177, 176.5 to 176, 169 to 168.5, 166 to 165.5, 159 to 157, 149 to 148.5, 143.5 to 143, 139 to 132, 131 to 130, 125.5 to 124, 122.5 to 122, 119 to 117	114
MW-10D	267 to 257, 234 to 230, 211, 202, 189 to 187, 176 to 174, 166 to 165, 164, 159 to 156, 155 to 154, 150, 149, 121 to 122, 118, 100, 91 to 82, 74.5 to 74, 69 to 65.5, 65, 63 to 61, 51 to 49, 48 to 47, 44 to 43, 41 to 39, 22 to 17, 16 to 14, 12 to 8.5, -4, -5, -8, -10, -13, -15, -19.5, -27, -33.5 to -35, -38 to -40, -44 to -45.5, -51.5, -53.5, -54, -59.5, -63 to -66, -70	-72
MW-11D	395 to 394, 391 to 392, 389 to 388, 380 to 379, 375 to 372, 368 to 366, 361 to 359, 353 to 345, 340 to 335, 333 to 329, 328 to 324, 322 to 321, 318 to 315, 311 to 309, 295 to 290, 283 to 281, 273 to 269, 265 to 264, 241 to 239, 233 to 231, 229 to 227, 219 to 217, 213 to 215, 209 to 211, 203 to 202, 191 to 189, 179 to 175, 159 to 156, 152 to 151, 149 to 148	140

The geophysical logging activities performed during the RI (BBL, March 1998), in conjunction with the geophysical logging performed in connection with the Time-Critical Investigation (GEC, October 1995), provide a basis to further characterize the orientation and spacing of fractures within the bedrock units in the site vicinity and, in conjunction with specific-capacity testing results, provide a quantitative basis to estimate the apertures of bedrock fractures capable of transmitting ground water. A review of the geophysical borehole data generated by GEC (October 1995) was performed by BBL to assist in the interpretation of the lithologic data and characterize potential fracture zones in the bedrock that could have an affect on hydraulic conductivity. The nine wells reviewed included: Well 1, Well 2, Well 3, Well 4, Well 6, MW-1, MW-2, MW-3, and MW-4. The borehole geophysical data for the nine wells reviewed consisted of one or more of the following logs: natural gamma; spontaneous potential (SP); caliper; single point resistance (SPR); temperature; and fluid resistivity. To further facilitate this evaluation, the available natural gamma and SP data have been presented on cross-sections D-F and G-G' (Figures 18 and 19, respectively). These sections cross the site from north to south and from west to east as indicated on the cross section location map (Figure 10). The interpretation based on the geophysical data is constrained due to the amount and type of data collected [e.g., four of the wells reviewed (MW-1, MW-2, MW-3, and MW-4) only had gamma logging performed], and the protective steel casing present in the wells.

Interpretation of the lithologic sequence using the natural gamma data is limited due to the variable nature of the bedrock stratigraphy at the site. Interpretation of the caliper, SP, and SPR data provides characterization of potential fracture zones in specific wells. The increase in caliper width, which correlates with a decrease in natural gamma, SP, and SPR, indicates a potential fracture zone at a depth of 410 to 440 feet below ground surface (BGS) in Well 1 (Figure 19). An increase in caliper width correlates with decreases in natural gamma, SP, and SPR, indicates a potential fracture zone at a depth of 120 to 130 feet BGS in Well 2 (Figure 19). In Well 4, an increase in caliper width correlates with a decrease in gamma, SP and SPR indicating a potential fracture zone from 210 to 250 feet BGS. Also, in Well 6 (Figure 18) a potential fracture zone at an approximate depth of 190 to 210 feet BGS is characterized by decreases in natural gamma and SP. The decrease in SP at a depth of 110 feet BGS in Well 6 is interpreted as a response from the water table (Figure 18).

Additional geophysical logging performed during the RI included mechanical caliper and digital borehole acoustic televiewer to log the deepest borehole at the MW-10 cluster location. The mechanical caliper log provided a continuous record of the approximate borehole diameter. The use of the caliper log also served to verify the stability of the borehole prior to using the acoustic televiewer in the borehole and to provide a secondary method of confirming the depth of significant features observed through other methods. The borehole televiewer is an acoustic imaging device that scans the interior of the borehole with acoustic energy and is used to digitally record reflections of the energy from the borehole wall. The data generated through the acoustic televiewer logging were obtained and reduced by COLOG, of Golden, Colorado, and presented in several forms including: an acoustic amplitude printout; tadpole and structure plots; and a fracture table summarizing the depth orientation and approximate aperture of the fractures identified in this borehole (BBL, March 1998).

The geophysical logging results provide a detailed measurement of the frequency and orientation of the in-situ bedrock fractures intersected by the MW-10D borehole. Approximately 359 in-situ fractures and/or joints were identified within the 307.45 linear feet of televiewer log at borehole MW-10D, indicating an average fracture spacing of 0.86 feet (26 cm) within the entire acoustically logged bedrock interval. These data are consistent with observations from bedrock core samples obtained from MW-10D, and suggest that the bedrock in the vicinity of the site is highly fractured. For the six, 30- to 40-foot long specific-capacity tested intervals of the bedrock at the MW-10D borehole, the fracture spacing ranged from 22 to 35 cm with a mean of 28 cm and a standard deviation of 5.4 cm.

The fractures identified using the downhole acoustic televiewer vary widely in orientation. The fracture dip directions generally lie within either of two orientation sets:

- Northwestward, subparallel to the dip of bedding; or
- Southeastward, approximately perpendicular to the bedding.

Because the dip directions of these two sets of fractures are opposite one another, the standard deviation of the dip direction is relatively high (108°), and the mean dip direction for the population of in-situ fractures identified at the MW-10D borehole, approximately due-south, south -1° east, differs considerably from the orientation of either of the two main sets of fractures. The mean unadjusted dip angle is 57° (ranging between 35 and 75° with a standard deviation of 15°).

COLOG notes that the fracture aperture estimates provided by acoustic televiewer may be exaggerated, and not always reliable (COLOG personal communications 1991). However, the specific capacity tests and the bedrock fracture spacing data from MW-10D provide a means to estimate the bedrock hydraulic fracture apertures. The calculation procedure of using the bedrock mean fracture interval, frequency, and interval transmissivity data to estimate mean aperture is described in detail in the RI Report. The procedure uses the parallel plate analogy (Harr, 1962; Zeigler, 1976), which assumes fluid flow occurs through smooth, closely spaced, parallel plates.

Transmissivity results from the specific capacity tests and boring observations at MW-10D were used for these calculations. In general the fractures used to determine the fracture interval spacing represent macroscale fractures, visible to the unaided eye. Intervals which were used in the packer testing for transmissivity determination were used for these calculations. The number of these fractures was determined from the boring logs. Estimates of the mean (individual) fracture transmissivity were computed by dividing the interval transmissivity by the number of fractures in that interval. Dividing the interval length by the fracture number provided an estimate of the mean fracture spacing, which assumes that the fractures are equally spaced along that interval. The mean fracture transmissivity is used to compute the mean fracture apertures using an inverted form of the parallel plate equation.

The mean fracture aperture ranges were calculated by BBL as 0.0081 to 0.080 cm (81 to 800 microns) for the six packer-tested intervals. Based on the calculated mean fracture apertures for each interval, the overall bedrock mean fracture aperture is estimated as 0.045 cm (450 microns), with a standard deviation of 0.030 cm (300 microns). The mean bedrock fracture porosity can be estimated as the mean fracture aperture (0.045 cm) divided by the mean fracture spacing (28 cm), which is 0.0016 (unitless) (0.16 percent).

To further characterize the bedrock units encountered at the MW-10D corehole, bedrock core samples from five selected depth intervals from were submitted during the RI to Core Laboratories of Houston, Texas, for analysis of bedrock matrix porosity, bulk density, grain density and total organic carbon. The depth intervals 272 feet, 315 feet, 331 feet, 351 feet, and 382 feet, were selected to be representative of the changing lithology encountered in this borehole. The results of these core analyses indicate bedrock matrix porosity ranging from 0.016 to 0.191 with a mean of 0.065 (unitless), bulk density values ranging from 2.18 g/cm^3 to 2.79 g/cm^3, and TOC ranging from 0.09 percent to 0.16 percent (BBL, March 1998).

5.2.1 General Hydraulic Gradients and Flow Directions

The depth to ground water at the site and in the immediate site vicinity has been observed to range from 105 and 115 feet below ground surface (bgs). To characterize horizontal ground-water flow gradients in the site vicinity, the ground-water elevation data presented in Table 9 were used to prepare a series of maps illustrating the potentiometric surface of the ground water within both shallow and deeper zones of the bedrock. The potentiometric surface maps for the shallow and deeper zones of the bedrock, based on the data from the August 19, 1996 water levels, are presented on Figures 20 and 21, respectively. The water level data collected on October 18, 1996 were used to prepare the potentiometric surface maps presented on Figures 22 and 23. Water level data collected on January 7, 1997, were used to prepare the potentiometric surface maps presented on Figures 24 and 25. Potentiometric surface maps (Figures 26 and 27) were prepared, based on the round of water level data collected on March 11, 1997. Water level data from October 1, 1997, were used to prepare the potentiometric surface maps presented on Figures 28 and 29. The most recent set of water level measurements from July 20, 1998 were used to prepare the potentiometric surface maps presented on Figures 30 and 31. To facilitate the consideration of potential structural influences upon hydraulic gradients, ground-water flow, and constituent migration in the site vicinity, the locations of geologic contacts and faults, as independently interpreted by C.R. Wood (Wood, 1972) and R.A. Sloto (Sloto, 1991), are also presented on each of the potentiometric surface elevation maps.

The August 19, 1996 and October 18, 1996 potentiometric surface maps utilized ground-water level measurements prior to the GWTS startup (Figures 20 to 21 and 22 to 23, respectively). Although the GWTS had begun periodic operation prior to obtaining the water level measurements on January 7, 1997, that were used to prepare the potentiometric elevation contour maps presented on Figures 24 and 25, the infrequent operation of the GWTS does not appear to have significantly impacted hydraulic gradients in the site vicinity. The apparent horizontal component of the ground-water flow direction interpreted from the hydraulic gradients illustrated during non-pumping GWTS conditions is generally toward the northwest, in the direction of Little Lehigh Creek with a steep hydraulic gradient from the direction of South Mountain to the south of the site and a gentler gradient extending toward the northwest of the site. An apparent low potentiometric surface feature(s) is observed on these potentiometric surface maps in both the shallow and deeper zones of the bedrock. This depression in the ground-water potentiometric surface, probably caused by the presence of a fault similarly trending to those identified by previous investigators, is located to the west of the site and extends to the north between the locations of the newly-installed well clusters MW-9 and MW-10. Ground water on the south side of the site appears to flow toward this depression, before migrating northward towards Little Lehigh Creek.

Generalized flow net diagrams were developed and superimposed on to the hydrogeologic cross sections (Figures 11B through 15B) to illustrate relevant information for understanding three dimensional ground-water flow in the site vicinity. The information presented on each hydrogeologic cross section include hydraulic head measurements, estimates of hydraulic conductivity for specific zones in the bedrock based on specific capacity tests, and flow net interpretations of the hydraulic gradients indicating the apparent direction of ground-water flow within each section. These flow net interpretations were also developed in consideration of the available geologic information as illustrated on Figures 11 through 15. The results of specific capacity tests performed during the advancement of the deep borehole at the MW-10 cluster identified hydraulic conductivity estimates ranging from 1.2 E-2 to 1.4 E-1 cm/sec for the intermediate depth intervals between approximately 300 and 430 feet below grade. The hydraulic conductivity estimates for the bedrock intervals both above and below these intervals were considerably lower, ranging from 9.5 E-5 to 9.2 E-4 cm/sec. Ground-water movement would be expected to occur preferentially within the intermediate bedrock depth intervals observed to have higher hydraulic conductivities.

5.2.2 Transmissivity and Hydraulic Conductivity

A summary of the ranges in transmissivity (T) and hydraulic conductivity (K) values calculated for the aquifer in the site vicinity is presented in Table 10.

Transmissivity (T) and hydraulic conductivity (K) calculated through reduction of the specific capacity data indicate a wide range of T and K. Estimates of T range from 60 (gpd/ft) to 120,000 gpd/ft, a difference of more than three orders of magnitude. Estimates of K vary from 9.5 x 10^{-5} centimeters per second (cm/sec) to 1.4 x 10^{-1} cm/sec, also a difference of more than three orders of magnitude. Since the specific capacity tests were performed at discrete bedrock intervals, and since ground-water flow through the bedrock is primarily along fractures (perhaps solution enhanced), this variation in T and K likely correlates with the presence or absence of permeable, interconnected fractures in the packed-off intervals.

The ranges of T and K calculated by reduction of aquifer performance testing data from both the SNR aquifer performance test and the testing completed as part of this RI are relatively consistent (BBL, March 1998). With the exception of data reduced from the short duration Phase I test conducted during the RI, values of T calculated from the SNR test (SNR, 1989) and the RI Phase II test ranged from 500 gpd/ft to 9,000 gpd/ft. The range in K is from 1.18 x 10^{-5} cm/sec to 4.77 x 10^{-3} cm/sec. While the estimated values of both T and K, based on the pumping test, appear to vary by more than two factors of 10, the values estimated, based on the specific capacity testing of specific depth intervals, range by more than four factors of 10. This suggests a greater degree of vertical vs. horizontal inhomogeneity. The relative small amounts of drawdown recorded in the observation wells MW-2 and MW-3 as compared to the much greater drawdowns observed in MW-1 and MW-4, also suggests the existence of anisotropy within the aquifer in the immediate site vicinity.

5.2.3 Stratigraphic, Structural and Hydraulic Conductivity Heterogeneity

Structural controls (as further modified by dissolution) are likely the cause of the apparent low potentiometric area observed on the potentiometric elevation maps, as suggested by the contour maps illustrating the topographic surface of both the weathered and competent bedrock (Figures 16 and 17) and the presence of faults inferred east and south of the site (Figures 3 and 4). The approximate mapped locations of these inferred faults are depicted on Figures 20 through 31. No direct evidence confirms these faults were encountered during the RI. The low surface elevations interpreted from both top of weathered bedrock and top of competent bedrock surface maps suggest the possible presence of paleochannels, which represent stream channels that incised into the surface of the two rock units. The presence of a thicker sequence of both overburden materials and weathered bedrock in the vicinity of the apparent depression in the ground-water potentiometric surface (evidenced on Figures 16, 17, and 20 through 31), as compared with the relatively smaller thickness of these units observed at the site and at the MW-9 well cluster location, also supports the paleochannel supposition (see cross sections C-C' and D-D' on Figures 13 and 14).

Vertical ground-water flow nets depicted on the each of the geologic and hydrogeologic sections (Figures 11 through 15 and 11B through 15B) also support the interpretation that the low potentiometric features observed in the map view are associated with a linear ground-water "drain" at an elevation of 0 to 100 feet above mean sea level within the bedrock (BBL, March 1998). This interpretation is also further supported by similar flow net diagrams using data from August 1996 as presented in a Technical Memorandum transmittal to the USEPA that supported the proposal for locating the MW-5 well cluster (BBL, September 1996).

5.3 Migration and Exposure

The components of the Conceptual Site Model relating to migration and exposure include the following information characterizing the source areas and materials; the Probable DNAPL Zone boundaries; solute transport considerations; and identification of potential receptors.

5.3.1 Source Areas and Source Materials

The sources of the dissolved constituents of concern observed in ground water in connection with this site include residual DNAPL believed to exist within an area of the fractured bedrock (Leithsville Formation). The extent of the Probable DNAPL Zone (the TI Zone) illustrated on Figures 9, 14B and 15B, for which a wavier of ARARs has been proposed, has very irregular horizontal and vertical dimensions. Therefore, for the purpose of estimating an approximate source area volume we have assumed simplified source area dimensions of approximately 350 feet long, 200 feet wide and 320 feet thick, extending vertically from the water table at a depth of approximately 120 feet to a total depth of approximately 440 feet below ground surface. While it is likely that the actual thickness of the Probable DNAPL Zone would be greater in some portions and less in other portions, an average thickness of 320 feet is a reasonable estimate for the purposes of the approximate volume calculations presented in this evaluation. This simplified approximation of the source area has been used as the basis for estimating DNAPL mass, as opposed to the irregular dimensions of the Probable DNAPL Zone, as defined in Section 4.0. In addition to the mass of DNAPL present within the source area, the mass of VOCs sorbed and dissolved within the source area also represent continuing sources of VOCs to the ground-water.

A small area of soil containing residual DNAPL has also been identified within the vadose zone near Well 2, however, the potential contribution of dissolved VOCs from this soil has been shown to be negligible in comparison to the contributions from the Probable DNAPL Zone.

5.3.2 Probable DNAPL Zone Boundaries

The constituent detected at the highest concentration in ground-water samples at the site is TCE. While the DNAPL at the site may contain several chemical components, TCE was selected for comparison with solubility criteria to delineate the Probable DNAPL Zone. This approach may be somewhat conservative, and may underestimate the Probable DNAPL Zone because the presence of other compounds in the DNAPL would reduce the effective solubility limit for TCE. Based on the 1 percent effective solubility limit guideline (USEPA, 1992), the ground-water quality observed at the site were sorted to identify the monitoring wells where the TCE concentrations exceeded 1 percent of the pure-phase TCE solubility limit of 1,100 mg/L. The following table summarizes the concentrations of TCE observed in selected ground-water samples at the site based on the most recent ground-water sampling event in January 1997 and the calculated percent of the single compound solubility for TCE in water.

Well ID	TCE Concentration (mg/L)[1]	Percent of TCE Solubility[2]
RW-3	490	44.5 percent
Well 2	420	38.2 percent
Well 4	140	12.7 percent
Well 3	100	9.1 percent
MW-4	45	4.1 percent
MW-1	17	1.6 percent

<u>Notes:</u>

[1] January 1997 Groundwater Sampling Event.

[2] Percent single-component solubility calculated based on TCE solubility of 1,100 mg/L.

Figure 9 shows the locations of wells indicating the likelihood of proximal DNAPL with respect to the 1 percent criterion. The distribution of wells that meet or exceed the 1 percent criterion indicates the horizontal extent of the Probable DNAPL Zone as indicated on Figure 9. The estimated vertical extent of the Probable DNAPL Zone, as indicated by dissolved TCE concentrations exceeding the 1 percent criterion, is illustrated on the cross sections presented as Figures 14B and 15B.

The Probable DNAPL Zone is consistent with the observations during advancement of the on-site soil borings. Based on the method of Feenstra, et. al. (November 1991), assuming a soil TOC value of 1 percent, and given the mean, measured soil porosity value of 0.48 (see Appendix J), any soil TCE concentration above 18 mg/kg would indicate an equilibrium pore-water TCE concentration above 11 mg/L (1 percent of the pure-phase TCE solubility). This condition was observed in a soil sample obtained from soil boring SB-7 (adjacent to Well 2), where TCE was detected at a concentration of 1,400 mg/kg, suggesting the probable presence of DNAPL in the overburden soil in the immediate vicinity of this boring. However, the extent of DNAPL in the overburden in the area of boring SB-7 (and Well 2) appears to be limited, as the field screening results (i.e., visual examination for sheen on drilling cuttings, Sudan IV dye test results and/or UV light screening) and soil analytical data from the surrounding borings (SB-19 through SB-26) did not indicate the presence of DNAPL.

The Probable DNAPL Zone illustrated on Figure 9 also includes the location of Well 3, where a dense black material was observed in the bottom of the well during the borehole video taping completed by GEC. Although pure separate phase TCE is a colorless liquid, the dense black material observed on the borehole video could be a direct observation of a DNAPL darkly colored through contact with pigments in the subsurface.

5.3.3 Solute Transport

The factors considered with regard to solute transport related to the site include: the nature and extent of the VOCs in ground water; estimates of the mass of VOCs present in the source area; impacts of matrix diffusion on contaminant fate and transport; and migration potential of the constituents of concern.

5.3.3.1 Nature and Extent of Ground-Water VOC Plume

The most frequently detected contaminants in ground water are: TCE; 1,2-DCE; VC; PCE; 1,1,2-TCA; and 1,1-DCE. TCE is the compound observed at the highest concentrations as well as the compound found to be most widespread at the Rodale site. The observed horizontal extent of TCE in ground water is clearly illustrated on the isoconcentration map presented on Figure 8. Although dissolved TCE concentrations at the site have been observed to range up to 570,000 µg/L, dissolved TCE concentrations in ground water have also been observed to decline below 5 µg/L within less than 700 feet downgradient of the site.

5.3.3.2 Estimated Dissolved, Sorbed, and DNAPL VOC Mass

This section presents the results of calculations regarding the mass of VOCs associated with the approximate source area at the site. Dissolved mass calculations have been performed based on observed concentrations of VOCs in bedrock monitoring wells. Sorbed mass estimates have been performed assuming equilibrium partitioning assumptions using geotechnical and geochemical parameters quantified during the completion of the RI. DNAPL mass has been estimated using a range of estimated bulk retention capacity for the bedrock DNAPL zone.

The purpose of this section is to estimate the relative magnitude of the VOC presence in the subsurface in the vicinity of the site in terms of the VOC mass and the equivalent volume of DNAPL. The technical basis for the VOC mass estimates presented below is modified from a method described by Kueper (August 1997).

<u>1) Mass of chemical component dissolved in ground water</u>

The mass of a given chemical component dissolved in ground water can be estimated using:

$$M_{A_t}=C_t\phi_{w_t}V_t$$

where M_{At} is the mass of the component dissolved in ground water within the approximate source area, C_t is the volume-averaged concentration of the component in ground water within approximate source area, ϕ_{wt} is the water-filled porosity of the bedrock within the approximate source area, and V_t is the volume of the approximate source area. This expression is valid for both porous and fractured media, under either saturated or unsaturated conditions.

Based on an average concentration of TCE in ground water within the approximate source area of 189 mg/L, an average bedrock matrix porosity of 0.065, and an estimated approximate source area volume of 634,000,000 L, the mass of dissolved VOCs in ground water within the approximate source area is estimated to be 7,789 kg.

<u>2) Mass of chemical component sorbed to aquifer solids</u>

The mass of a given chemical component sorbed to the soil or rock matrix can be estimated using:

$$M_{S_t}=C_tK_{d_t}\rho_{b_t}V_t$$

where M_{Si} is the mass of sorbed chemical component within approximate source area, C is the averaged concentration of TCE in ground water within approximate source area, K_d is the soil-water distribution coefficient within approximate source area, ρ_{bi} is the dry bulk density of the medium within approximate source area, and V_i is the volume of the approximate source area. This expression assumes equilibrium partitioning between the aqueous and solid phases. The distribution coefficient, K_d, is often estimated using $K_d = K_{oc}f_{oc}$ where K_{oc} is the organic-carbon based partition coefficient (126 L/kg for TCE), and f_{oc} is the fraction of organic carbon present in the medium (average of 0.0012 for the bedrock cores tested) (Pankow and Cherry, 1996).

Based on the average concentration of dissolved TCE in ground water within the approximate source area of 189 mg/L, a soil-water distribution coefficient of 1.5×10^{-7} L/kg, a mean bulk density of 2.6 g/L, and an estimated approximate source area volume of 634,000,000 L, the mass of sorbed VOCs on rock media within the approximate source area is estimated to be 47,070 kg.

3) DNAPL Mass

The mass of DNAPL in the subsurface can be estimated using:

$$M_{N_i} = R_i V_i \rho_n$$

where M_{Ni} is the mass of DNAPL present within approximate source area, R_i is the bulk retention capacity of the medium within approximate source area, V_i is the total volume of medium within the approximate source area, ρ_n is the chemical component mass density of the DNAPL (1.46 g/mL for TCE). It is important to recognize that V_i includes lenses, laminations, and fractures void of DNAPL as well as those containing DNAPL within the overall volume of subsurface impacted by DNAPL within the approximate source area. For DNAPL in fractured media, R_i depends on the fracture aperture and spacing characteristics, which have been quantified at the site during the completion of the RI. The estimated value of R_i in the Leithsville Formation ranges from 1.6×10^{-4} to 6.4×10^{-4} (Kueper, personal communication, July 1998).

Based on the above estimated values, the mass of DNAPL present within the approximate source area is estimate to range between 148,102 kg and 592,410 kg.

5.3.3.3 Impact of Matrix Diffusion on Contaminant Fate and Transport

The impact of matrix diffusion on fate and transport of constituents related to this site is a significant issue which relates to the appropriateness of applying a TI ARAR Waiver for the site. Therefore, an analysis has been prepared by Dr. Kueper of matrix diffusion with respect to fate and transport for this site and is presented as Attachment 1.

The specific purpose of the analysis performed by Dr. Kueper was to examine the impact of matrix diffusion on the fate and transport of TCE in fractured bedrock at the Rodale Manufacturing site. The analysis makes use of an exact analytical solution which solves for solute concentration in both open fractures and the rock matrix. This model adopts the simplifying assumptions of parallel, equally-spaced fractures subject to a uniform ground-water velocity field.

The initial set of simulations were run assuming a constant TCE source concentration of 285 ppm at the inlet to a 100 meter long flow system. These simulations indicate the matrix blocks along the entire flow path would be nearly saturated after thirty years of continuous exposure as a results of inward matrix diffusion from fractures. This simulation was run using average values of fracture spacing, fracture aperture, matrix porosity, matrix dry bulk density, and matrix fraction organic carbon based on average values presented by BBL (1998, March).

A second set of simulations was then run assuming that a pump-and-treat system is operated 100 meters downgradient of the TCE source and that the source is completely removed. This would be the equivalent to the injection of clean water at the inlet to the flow system after 30 years of the previously simulated continuous exposure. The second set of simulations are also based on the average bedrock characterization parameters presented by BBL (March 1998). These simulations suggest that the concentration of TCE in open bedrock fractures may be reduced to below 1 ppb along the flow path after approximately 30 years of continuous clean water flushing. It should be recognized that the analytical solution used in this analysis cannot account for the actual complexities of the bedrock flow system at the Rodale site. Furthermore, average bedrock parameters were used in this analysis. Therefore, portions of the flow system would be expected to exhibit both shorter and longer diffusion time-scales than those simulated by this study.

5.3.3.4 Migration Potential of Chemical Constituents

The dissolved VOCs observed in ground water in association with this site would be anticipated to migrate within the fractured bedrock aquifer. However, bedrock matrix porosity is an important factor influencing the rate of migration of constituents through the bedrock. Chemical constituent velocities (v_c) in bedrock are related to the average linear ground-water velocity as $v_c = v/R_b$, where v is the average linear ground-water (advective) velocity; and R_b is the bedrock retardation factor, which in a fractured, porous medium, is dependent primarily upon the influence of matrix diffusion. There is also a smaller component of bedrock retardation resulting from sorption to organic carbon in the bedrock. The bedrock retardation factor caused by matrix diffusion is a function of the bedrock matrix porosity and fracture porosity, as follows (Kueper, personal communication, August 1995):

$$R_b = n_m / n_f$$

where,
n_m = bedrock matrix porosity; and
n_f = bedrock fracture porosity.

Given the mean bedrock matrix porosity of 0.065 from laboratory data (as discussed earlier in this section) and the calculated fracture porosity of 0.0016 (also discussed earlier in this section), the computed mean retardation factor due to matrix porosity was computed to be 40.6. Thus, the average linear velocity of VOC migration in ground water may be reduced by approximately a factor of 40 due to matrix diffusion.

5.3.4 Contaminant Transport Pathways

The primary pathway of potential concern regarding the transport of contaminants from this site is migration with ground water through the fractured bedrock aquifer beneath the site. Ground-water monitoring data indicate a plume of dissolved VOCs in ground water at concentrations at or above MCLs extends from the site toward the northwest as far as While a secondary pathway is related to the leaching of residual contaminants from subsurface soil in the vadose zone surrounding former disposal Well 2, these contaminants would migrate vertically into the ground-water, therefore, further migration of these contaminants would be also dependant on the primary pathway of migration with ground water.

An existing ground-water recovery and treatment system (GWTS) was installed as an interim remedy to mitigate off-site migration of dissolved contaminants. Operation of the GWTS appears to be resulting in substantial drawdown in the area surrounding the pumping wells. This is demonstrated by the potentiometric surface observed in the recovery and observation wells at the site, as illustrated in the contour maps presented as Figures 30 and 31. Although the effectiveness of the GWTS with regard to capture of ground water within the Probable DNAPL Zone has not yet been clearly demonstrated by the available data, future modification of the GWTS (i.e., the installation of an additional recovery well in replacement for existing well MW-4) to be implemented in conjunction with the overall site remedy would be designed to establish hydraulic control of the dissolved contaminants with the potential to migrate from the site by this pathway. An expansion of the existing monitoring well network may also be necessary to adequately demonstrate hydraulic control.

5.3.5 Potential Future Receptors

As detailed in the draft Human Health Risk Assessment (BBL, October 1998), potential future receptors identified in connection with this site might include the potential for exposure to contaminated ground water in the event that one or more ground-water extraction wells were to be installed and operated within the site or the downgradient portion of the aquifer containing dissolved levels of VOCs in excess of MCLs.

6. Restoration Potential for Site

6.1 General

This section presents an evaluation of the restoration potential for the site and provides the basis for the interpretation that ground water restoration is technically impracticable within the proposed TI zone. Following a general discussion of the challenges to remediating the Rodale Manufacturing site, this section includes discussions of the source materials, previous remedial actions, previous DNAPL removal efforts, the effectiveness of the existing pump and treat system, other potential remedial technologies, and a remedial time frame analysis.

The technical challenges to remediating contaminated ground-water include many complex factors related to site hydrogeology and chemistry. One of the most difficult of these challenges is the problem presented by DNAPLs. A recent USEPA study indicates that DNAPLs may be present at up to 60 percent of NPL sites, are often very difficult to locate and remove from the subsurface environment, and are expected to continue to contaminate ground-water for many hundreds of years despite best efforts to remedy them. The prevalence and intractability of DNAPL contamination are among the principal reasons the TI guidance document was developed by USEPA (USEPA, September 1993).

Most saturated overburden and bedrock deposits contaminated by DNAPLs cannot be remediated to typical concentration-based cleanup goals (USEPA, September 1993), which would require that virtually all of the DNAPL be removed from a site (Kueper, pers. com. with M.J. Gefell, October 1997). Research and experience acquired during the past 10 years have shown that while partial DNAPL removal may be possible at some sites, removing sufficient DNAPL to achieve concentration-based cleanup goals is not technically practicable due to an inability to contact hydraulically all residual and pooled DNAPL present in the subsurface. This inability stems from the fact that natural deposits are in general heterogeneous, resulting in preferential flow of injected fluids and incomplete contact with the target DNAPL. In fractured porous media, the process of matrix diffusion also serves to impede the effectiveness of remedial technologies further. At present, in situ ground-water cleanup technologies to restore ground-water to MCLs have not been successfully applied at sites with known moderate to large quantities of DNAPL present below the water table (Kueper, pers. com. with M.J. Gefell, September 1997).

In support of the TI Evaluation, the RI Report included a presentation of data relevant to the TI Evaluation including: 1) the estimated three-dimensional volume of the Probable DNAPL Zone, and 2) the estimated total VOC mass dissolved, sorbed, or present as NAPLs in the overburden and bedrock. As proposed in the USEPA-approved RI Work Plan (BBL, May 1996), data were obtained to support a "front-end" TI decision for the site, in accordance with Section 4.2 of the TI guidance document (USEPA, September 1993). A front-end TI decision is made before implementing the overall site remedy and applies in certain cases when adequate, detailed site characterization has been performed. In accordance with the TI guidance document (USEPA, September 1993), the RI characterized the most critical limitations to ground-water restoration, including the presence, quantity, distribution, and properties of DNAPL; geologic formation heterogeneity and solute transport characteristics; and bedrock fracture characteristics.

Given the field observations and laboratory confirmation of DNAPL in the overburden and bedrock, and the observed presence of DNAPL within bedrock at the disposal wells during their initial clean out (Correspondence from Willard Wade, Gilbert/Commonwealth Engineers and Consultants, to Allen Williams, Foley and Larder; October 16, 1981), ground-water restoration within the DNAPL zone can be considered technically impracticable.

This judgement is based on the presence of a large volume on DNAPL believed to exist within an area of fractured bedrock (Leithsville formation), approximately 350 feet long, 200 feet wide and 320 feet in depth (255 feet into bedrock). In-situ flushing remedial efforts would be seriously limited at the Rodale site due to the low mean hydraulic conductivity in the bedrock which varies by orders of magnitude both vertically and horizontally. The bedrock fracture and matrix characteristics indicate that the bedrock hydraulic conductivity is extremely heterogeneous on a minute scale, and that the matrix has a significant storage capacity for VOCs, which will slowly diffuse back out of the matrix and will serve as a long-term VOC source to ground-water.

At the Rodale site, DNAPL-zone restoration can be considered especially difficult due to the nature of the DNAPL release. In qualitative terms, the release of DNAPL at the Rodale site can be classified as a large-volume, long-duration, continual release to a heterogeneous, low- to moderate-permeability medium. According to the USEPA TI guidance document (USEPA, September 1993) and other sources (WCGR, 1991; Cohen and Mercer, 1993; Pankow and Cherry, 1996; Kueper, pers. com. with M.J. Gefell, 1997), these characteristics increase the difficulty of ground-water restoration and merit a TI decision for the proposed TI zone.

The proposed TI zone includes only the zone of the aquifer in which DNAPLs likely reside. This remedy will be specified in the ROD to address the off-site regulatory VOC plume, and will serve as the required containment system for the proposed TI zone.

6.2 Assessment of Source Materials

The Rodale site property had been used for commercial or manufacturing purposes since at least the 1920s, by various owners. In 1986, Square D closed manufacturing operations at the site. Previously used waste disposal wells were identified during facility demolition activities.

Specific operational practices prior to 1961 are largely unknown. Pennsylvania Department of Environmental Protection (PADEP) files indicate that under Rodale Manufacturing's operation of the facility, several wells were used for disposal of various wastes. PADEP files indicated that in 1962, approximately 3,000 gallons per day (gpd) of wastewater, including rinse water from copper and zinc plating and acid brass dipping, were discharged to a 452-foot deep borehole (subsequently identified as Well 1) located in the former Courtyard Area (Figure 2). Borough of Emmaus files indicate that the electroplating room was connected to the sanitary sewer by January 1967. Rodale's operation continued until 1975 when the business was sold to Bell Electric.

Long-time employees of Rodale Manufacturing indicated that two other wells (Well 2 and Well 3) were also used for disposal purposes, and the locations of these wells were identified. A monitoring well (Well 4) was installed to a depth of 342 feet below ground surface (bgs) in June 1981 by Gill Enterprises on behalf of Square D. Water samples collected from the monitoring well and the three identified disposal wells revealed the presence of varying concentrations of volatile organic compounds (VOCs), metals, and cyanide.

The source of the dissolved constituents of concern observed in ground water in connection with this site include residual DNAPL believed to exist within an approximate source area in the fractured bedrock (Leithsville Formation) estimated to be 350 feet long, 200 feet wide and 320 feet in depth. For the purpose of the proposed ARAR waviver, the Probable DNAPL Zone (TI Zone) has been more concisely defined as discussed in Section

4.0 and as illustrated in Figures 9, 14B, and 15B. In addition to the mass of DNAPL present within the approximate source area, the mass of VOCs sorbed and dissolved within the approximate source area also represent continuing sources of VOCs to the ground-water.

Based on the calculations presented in Section 5, the total mass of VOCs present as dissolved VOCs, as sorbed VOCs, and as DNAPL within the approximate source area is estimated to range between approximately 203,000 kg and 647,000 kg.

In addition to the DNAPL source, which will take hundreds of years to dissolve (see Section 6.6 below), chemicals diffused into the bedrock matrix will take an additional period of time to diffuse back out of the matrix and clean up to ground-water regulatory criteria, even after the DNAPL is completely dissolved.

6.3 Previous Remedial Actions

Four previous remedial actions have been performed at the Rodale site, as summarized below.

VOC Removal from Ground-Water - 1984 through 1989

In 1984, operation of an air-stripping tower commenced for removal of VOCs from ground-water pumped from Well 1. A National Pollutant Discharge Elimination System (NPDES) permit for surface discharge of treated ground water was issued by the PADEP. The pumping and air-stripping activities continued until 1989 when Square D proceeded with demolition of Building D and discontinued operation of the interim ground-water pumping and air stripping program. Ground-water monitoring results obtained between 1981 and 1988 indicated that the pumping and air-stripping activities were effective in lowering VOC concentrations in Well 1 from hundreds of parts per million (ppm) to less than 1 ppm (SNR, March 1989).

Ground-Water Monitoring Plan - 1988

Following closure of the facility by Square D in 1986, investigative and remedial activities continued. In 1988, Square D retained SNR Company (SNR) of Laguna Hills, California to prepare a Ground Water Monitoring Plan. During preparation of the plan, SNR installed four ground-water monitoring wells (originally designated SW-A through SW-D but now referred to as MW-1 through MW-4) around the perimeter of the facility. The wells were screened near the water table. In 1989, the south wing (Building D) was demolished to provide space for additional remedial activities. During demolition, a well (designated WW-08, 6 feet in diameter and approximately 55 feet in depth) was discovered. Two fuel oil underground storage tanks (USTs) were also removed (Figure 2).

CERCLA Response Action - 1989

In January 1989, NUS Corporation conducted a site Inspection (SI) on behalf of the USEPA at the site (NUS, November 1989). The SI consisted of the collection of water samples from the three former on-site disposal wells, four on-site monitoring wells, three of the six Borough of Emmaus water supply wells, and three residential wells. In November 1989, the PADEP collected several water samples from wells located downgradient of the study area, including one Borough of Emmaus water supply well (PSW-7) and five downgradient private wells in Lower

Macungie Township. A hydrogeologic investigation was completed by Roy F. Weston, Inc. (Weston) during 1989. In 1990, a monitoring/recovery well (RW-1) was installed at the site and another monitoring/recovery well (RW-2) was partially completed with the installation of surface casing. Final completion was to be based on the anticipated use of the well. The locations of all known disposal, production, recovery, and monitoring wells at the site are indicated on Figure 2. The significant findings of these investigations are summarized in Section 1.2.4 of the Feasibility Study report.

Non-Time Critical Interim Response Action: Ground-Water Treatment System - 1994

A separate AOC for a Removal Response Action (RRA) (USEPA Docket No. 111-94-15-DC) for a site GWTS and related tasks was also executed between the USEPA and Square D, effective September 30, 1994. The document entitled "Supplement I to the Time-Critical Work Plan for the Rodale Manufacturing site, (GEC, February 1995)", which includes a conceptual design for the ground-water pump-and-treat system, was prepared and submitted to the USEPA pursuant to this AOC. Supplement I also included a presentation of site conditions, an evaluation and screening of treatment technologies, and the conceptual design of the subsequently constructed ground-water pump-and-treat system. These Non-Time Critical Interim Response Action activities are discussed in more detail in the Feasibility Study report.

The construction of the GWTS was completed and an initial period of system start up was implemented between August 19 and 21, 1996, during which BBL performed continuous water level monitoring for aquifer characterization purposes. The GWTS has been in operation under automatic conditions as of February 5, 1997.

The ground-water treatment system was constructed at the site to treat the ground water recovered from the four existing wells Well 3, Well 4, RW-3, and MW-4 (referred to within the context of the GWTS as EXWP-1, EXWP-2, EXWP-3, and EXWP-4, respectively). However, recovery from the existing well MW-4 was discontinued due to lack of sufficient available drawdown for operation of this well. The GWTS is designed to operate at an average flow rate of between 30 and 45 gpm. The GWTS was designed for a maximum flow rate of 90 gpm. Flow rates to the GWTS from Well 4, Well 3, and RW-3 have averaged 13.5 gpm, 9 gpm, and 7.5 gpm, respectively. The GWTS includes the following components:

- an equalization tank;
- *a liquid/solid separation unit and sludge handling equipment;*
- an air stripper;
- liquid phase granular activated carbon units; and
- a regenerative vapor phase adsorber unit (Thermatrix™ Unit).

Treated ground water is discharged to a storm sewer located on-site which discharges to the Unnamed tributary to Liebert Creek pursuant to a NPDES permit issued by PADEP.

6.4 Effectiveness of Existing Pump and Treat System

The existing GWTS began operation at the site in September 1996 and has been operating consistently at or near its intended production rate of 30 to 45 gallons per minute (gpm) since August 1997. Throughout this initial period of operation the GWTS has met required treatment objectives, extracted over 21 million gallons of ground water and has recovered in excess of 3,500 kg of TCE from the source area. Based on the current rates of ground-water extraction and TCE recovery, the GWTS is recovering approximately 250 kg of TCE per month.

The operation of the GWTS is also creating a significant drawdown of the potentiometric surface around the source area recovery wells at this site. The shallow and deep potentiometric surface maps (Figures 26 - 27, 28 - 29, and 30 - 31, respectively) depict conditions on dates when the GWTS has been operating (March 11 1997, October 1, 1997 and July 20, 1998, respectively). As can be observed by the closed potentiometric contours, and the artificial depression producing inward hydraulic gradients around the site property, the potentiometric maps empirically demonstrate that the GWTS has produced a drawdown of the potentiometric surface in both the shallow and deep zones of the bedrock, although the drawdown of the potentiometric surface in the deeper zone is more pronounced (as expected based on the extraction well screen locations). The drawdown of the potentiometric surface at shallower depths is less clearly defined. The existing groundwater treatment system and the area of hydraulic containment will be better defined following the installation of an additional monitoring well and the replacement of pumping well MW-4 as part of the remedial action for the site.

The need to augment the GWTS through the installation of a recovery well to replace the existing well MW-4 (EXW-4) is anticipated, as the existing MW-4 has not been consistently operated due to insufficient available drawdown resulting in poor yield.

6.5 Potential Remedial Technologies

It is currently recognized that most saturated overburden and bedrock deposits contaminated by DNAPLs cannot be remediated to typical concentration-based clean-up goals (USEPA, September 1993). Achieving typical concentration-based clean-up goals for groundwater requires that virtually all of the DNAPL be removed from a site (Kueper, pers. com., October 1997). Research and experience acquired during the past 10 years has shown that while partial DNAPL removal may be possible at some sites, removing sufficient DNAPL to achieve concentration-based clean-up goals is not technically practicable. The primary reason for this is an inability to hydraulically contact all residual and pooled DNAPL present in the subsurface. This inability stems from the fact that natural deposits are in general heterogeneous, resulting in preferential flow of injected fluids and incomplete contact with the target DNAPL. In fractured porous media, the process of matrix diffusion serves to further impede the effectiveness of remedial technologies. At present, there have been no successful applications of in-situ groundwater clean-up technologies where it is known that moderate to large quantities of DNAPL are present below the water table and ground water was restored to MCLs (Kueper, pers. com. with M.J. Gefell, September 1997).

At the Rodale site, DNAPL-zone restoration can be considered especially difficult due to the nature of the DNAPL release. In qualitative terms, the release of DNAPL at the Rodale Manufacturing site can be classified as a large-volume, long-duration, continual release to a heterogeneous medium. According to the USEPA TI guidance document (USEPA, September 1993) and other sources (WCGR, 1991; Cohen and Mercer, 1993; Pankow and Cherry, 1996; Kueper, pers. com. with M.J. Gefell, 1997), these characteristics increase the difficulty of ground-water restoration.

Potential remedial technologies that may be considered to remove mass within the Potential DNAPL zone at the site include the following:

- Hydraulic containment;
- Physical containment;
- Permeable treatment walls;
- Biodegradation;
- Alcohol flooding and cosolvent flushing;
- Surfactant flushing;
- Air sparging;
- Pump-and-treat;
- Waterflooding;
- Steam flooding;
- Oxidant flooding; and
- Natural attenuation.

A description of each technology listed above and their effectiveness at DNAPL-Zone restoration are presented below.

6.5.1 Hydraulic Containment

Hydraulic containment involves the placement of either vertical pumping wells, horizontal pumping wells, or pumping trenches on the downstream boundary of the zone of technical impracticability. The objective of hydraulic containment is to intercept contaminated groundwater and prevent further migration to downgradient or adjacent areas where groundwater restoration can be achieved. Hydraulic containment is typically considered a reliable means of intercepting contaminated groundwater, and is not considered a DNAPL remediation technology. The performance of such systems can be monitored in a relatively simple fashion by measuring hydraulic heads and groundwater concentrations. Depending on geology and hydrogeology, such systems may need to be augmented with the use of physical barriers (Kueper, October 1998).

Hydraulic containment has been evaluated for use in bedrock at the site. It should be noted, however, that even aggressive pumping of groundwater in DNAPL zones will not significantly shorten the lifespan of residual and pooled DNAPL present below the watertable. In addition, the implementation of a hydraulic containment system at the site must consider the risk of mobilizing DNAPL pools beyond the current probable DNAPL zone. Careful consideration will need to be given to the placement of hydraulic containment systems to ensure that the risk of further pool mobilization is kept to a minimum (Kueper, October 1998).

It can be concluded that hydraulic containment is a suitable method for containing the zone of technical impracticability at the site. Although hydraulic containment methods cannot restore groundwater quality within the zone of technical impracticability, they can eliminate the further downstream migration of dissolved contaminants and allow the severed portion of the aqueous plume to attenuate and meet ARARs.

6.5.2 Physical Containment

Physical containment refers to the placement of hydraulic barriers, such as sealable joint sheet piling, slurry walls, or injection grout walls around the zone of technical impracticability. The objective of such barriers is to mitigate contaminant transport further downgradient. Physical barrier systems typically require small to moderate amounts of groundwater pumping from within the enclosure to offset infiltration and to ensure that no outward leakage occurs. Physical barriers can also be constructed without a barrier at the upgradient end. In such cases a larger amount of groundwater pumping will be required to offset both infiltration and upgradient groundwater flow (Kueper, October 1998).

The use of slurry walls and sealable joint sheet piling are not feasible technologies for physical containment in bedrock. Injection grouting could be considered a feasible method of physically containing ground water in some fractured bedrock settings. As in overburden, a small amount of groundwater pumping from within the enclosure is usually required to offset infiltration and to ensure that outward leakage is not occurring. Physical capping can be considered as a method of reducing ground surface exposure to contaminants, and to reduce infiltration.

The use of physical barriers can be evaluated as a means of eliminating mass flux leaving the zone of technical impracticability.

6.5.3 Permeable Treatment Walls

In-situ permeable treatment walls have been proposed as a means of passively treating certain organics found in contaminated groundwater. These walls involve the construction of a trench into which a reactive material is placed. Contaminants are degraded while flowing through the trench. The use of a permeable treatment wall does not shorten the lifespan of residual and pooled DNAPL. The rate at which contaminants are delivered to the trench is determined by solubility and mass transfer constraints governing DNAPL dissolution. Permeable treatment walls are therefore a means of plume interception, and should not be regarded as a DNAPL remediation technology.

To date, zero valent iron has been identified as a material suitable for the degradation of certain chlorinated organics such as trichloroethylene (TCE) and tetrachloroethylene (PCE). It is understood that the degradation of these compounds proceeds abiotically and follows pseudo-first order kinetics. The reaction is electrochemical in nature, with iron being oxidized to $Fe2+$, and the chlorinated organic compound reduced to less chlorinated or non-chlorinated hydrocarbons (Gillham, 1998). The reaction rate depends on the specific surface area of the iron and the particular organic compound being targeted. Half lives for many common groundwater contaminants are on the order of minutes to hours.

The technology is currently limited to application in overburden deposits, although methods of injecting iron as part of a gel are currently being developed for application in fractured rock. Current concerns regarding the long-term effectiveness of this technology include the formation of precipitates, and the associated reduction in porosity. The use of a permeable treatment wall is not considered a suitable means of containing the zone of technical impracticability.

6.5.4 Biodegradation

In-situ biodegradation has the potential to degrade certain organic compounds under both aerobic and anaerobic conditions (Pankow and Cherry, 1996). This technology is generally suited to low concentrations of organics in groundwater and therefore is not suitable as a means of removing residual and pooled DNAPL. This does not imply, however, that substantial amounts of degradation are not occurring within the DNAPL zone.

There is very little evidence that sufficient biodegradation can occur to significantly reduce the lifespan of DNAPL *in the subsurface. There is evidence, however, that biodegradation will remove aqueous phase contaminants derived* from DNAPL sources (Kueper, October 1998). Biodegradation should not be evaluated further as a means of restoring groundwater within the Probable DNAPL Zone. Biodegradation will contribute to natural attenuation of groundwater contaminants downstream of the Probable DNAPL Zone, however, and is evaluated further in the FS.

6.5.5 Alcohol Flooding and Cosolvent Flushing

Alcohol flooding has been proposed as a potential DNAPL remediation technology because of the fact that many alcohols are mutually miscible in both water and DNAPL. If enough alcohol is added to a DNAPL-water system, one fluid phase will result as the interfacial tension is reduced to zero. Because alcohol has the ability to reduce interfacial tension to zero, it is theoretically possible to remove large volumes of DNAPL using slugs of alcohol that are less than one pore volume in size. Several alcohols have been identified as suitable for the removal of various DNAPLs (Kueper, October 1998).

Various researchers have demonstrated that alcohol flooding can bring about significant amounts of DNAPL removal in one-dimensional laboratory experiments (e.g., Brandes 1992, WCGR 1995). To date, there have not been any three-dimensional studies of alcohol flooding as a DNAPL removal technology. The alcohols suitable for DNAPL removal are less dense than water. It will therefore be difficult to allow alcohol to contact any residual or pooled DNAPL present in the lower portions of the bedrock at the Rodale site. Buoyancy will result in rapid upward movement of alcohol unless very small well spacings and high injection pressures are employed. While the phase behavior of alcohol systems is extremely favorable for DNAPL removal, the density and viscosity of alcohol results in poor deliverability. Major advances will need to be made to overcome the complicating effect of heterogeneity before consideration can be given to full-scale application at actual sites (Kueper, October 1998).

It appears that alcohol flooding may be suited to the removal of DNAPL from small, localized areas where the injection-withdrawal process can be controlled. Alcohol flooding is currently in the developmental stage, and is not ready for off-the-shelf implementation. No data exist examining the ability of alcohol to remove complex, multicomponent DNAPL such as that present at the Rodale site. Also, the high degree of heterogeneity present in overburden and bedrock at the site will hinder the ability of injected fluids to contact all regions of the subsurface containing DNAPL. It is also not clear whether or not regulatory approval can be obtained for injecting large volumes of alcohol into the subsurface. Alcohol flooding should not be considered further at this time as a means of removing DNAPL from the potential DNAPL zone in either overburden or bedrock.

Several authors (e.g., Pankow and Cherry, 1996) have coined the term 'cosolvent' flooding in reference to the use of alcohols. Cosolvent flooding generally refers to the injection of low concentrations (e.g., 1% - 5% by volume) of alcohol such that the system of interest remains as a two phase (DNAPL-water) system. The low concentrations of alcohol, however, serve to increase the solubility of DNAPL in aqueous solution (hence a cosolvent effect). The degree of solubility enhancement will be compound specific. In a cosolvent flood, many pore volumes of cosolvent need to be flushed through the DNAPL zone to accelerate dissolution. Unlike with the injection of high concentrations of alcohol (70% - 90%), no DNAPL mobilization takes place. Co-solvent flooding will exhibit tailing, typically well above clean-up levels, due to pore-scale and field-scale limitations to mass transfer. Co-solvent flooding will also lead to an increase in the rate of contaminant diffusion into the rock matrix in bedrock. To date, no experiments have been performed to demonstrate that cosolvent flooding can bring about aquifer restoration at a DNAPL site. Cosolvent flooding should not be evaluated further at this time as a means of restoring groundwater within the potential DNAPL zone in either overburden or bedrock (Kueper, October 1998).

6.5.6 Surfactant Flushing

Chemical surfactants (surface active agents) are typically long-chain molecules composed of a strongly hydrophilic end group and a strongly hydrophobic carbon tail. Surfactants are generally grouped into three primary classes depending on the nature of the particular hydrophile-hydrophobe combination: anionic, cationic, and non-ionic. Once surfactants are added to an aqueous solution, they will tend to be attracted to any liquid-liquid interfaces that are present. In a DNAPL-water system, the hydrophobic portion of a surfactant molecule will be attracted to the DNAPL phase, while the hydrophilic group will remain attracted to the aqueous phase. This results in an alteration of a number of properties, including a lowering of DNAPL-water interfacial tension (Kueper, October 1998).

If a sufficient quantity of surfactant is added to aqueous solution, aggregates of monomers called micelles will form. The concentration at which micelles begin to form is referred to as the critical micelle concentration (CMC). Micelles are configured with the hydrophobic tails of individual monomers pointed inwards, giving rise to a strongly hydrophobic interior into which organic contaminants can be entrained. The presence of micelles in the vicinity of DNAPL will give rise to an enhanced aqueous solubility of the DNAPL. This process of micellar solubilization is therefore capable of accelerating the rate of DNAPL dissolution into flowing groundwater. With proper matching of surfactant to DNAPL, the aqueous solubility of typical DNAPL compounds such as trichloroethylene (TCE) and tetrachloroethylene (PCE) can be increased by two to three orders of magnitude. Surfactant chemistry is discussed further by West and Harwell (1992).

While surfactants have the ability to increase the aqueous solubility of many sparingly soluble organics, the process of DNAPL dissolution into surfactant solution is typically rate limited, showing a dependence on a number of factors including groundwater flow rate. The implication of this is that contaminant concentrations in recovered groundwater during a surfactant flood will exhibit a slow, gradual decline towards clean-up levels.

Surfactant flushing is not suitable for application in bedrock at the Rodale site because of the unacceptable risk of mobilizing DNAPL pools deeper into the subsurface. In addition, increasing contaminant concentrations upon exposure to surfactants will increase the concentration gradient into the matrix, accelerating the transfer of mass from open fractures to the rock matrix. This same concern applies to alcohol flooding. Application of surfactant flushing and alcohol flooding may therefore increase the amount of time required to remediate bedrock, since clean-up time scales would be partially governed by the rate at which contaminants can diffuse back out of the porous matrix.

6.5.7 Air Sparging

Air sparging involves the injection of air into overburden deposits to promote the transfer of volatile contaminants from groundwater into the flowing air phase. The contaminant laden air is then collected in the unsaturated zone using vacuum extraction wells. The success of air sparging is dependent upon the ability to uniformly distribute air through the subsurface. In homogeneous deposits, the majority of air flow will occur in the immediate vicinity of the sparging well. This follows from the fact that air is significantly less dense than water, resulting in a strong upward driving force. Air sparging in homogeneous deposits will therefore require very small well spacings.

In heterogeneous deposits, it has been demonstrated (WCGR, 1995) that air flow is not uniform through- the subsurface. Air is non-wetting with respect to water and has a surface tension of approximately 0.072 N/m. As a result, rising air will be impeded by the presence of finer grained lenses and laminations. Air will pool below these lenses and flow laterally underneath them, resulting in large regions above the lenses which are not contacted by the rising air. Mass transfer from these stagnant regions to the rising air will be diffusion limited. It follows that while air sparging will certainly remove mass from the subsurface, long periods of tailing are to be expected in response to diffusion limited mass transfer from zones not contacted by injected air (Kueper, October 1998).

Except for exceptionally homogeneous sites, it can be concluded that injected air will largely by-pass zones of residual and pooled DNAPL. Recall that such zones will form above lower permeability horizons, the bottom of which will be impermeable to the rising air. Mass transfer from DNAPL to air will be primarily through groundwater, a process that will be constrained by the rate of aqueous phase diffusion. Air sparging can therefore not be regarded as a DNAPL removal technology. Air sparging should not be evaluated further as a means of removing DNAPL from the potential DNAPL zone in either overburden or bedrock.

6.5.8 Pump-and-Treat

Pump-and-treat refers to the extraction of contaminated groundwater followed by ex-situ treatment. It is now well recognized that although pump-and-treat could be an effective method of restoring that portion of an aquifer impacted by dissolved constituents once the source (e.g., the DNAPL Zone) has been isolated, this technology is ineffective at restoring groundwater in the presence of DNAPL because of the long time periods required to dissolve residual and pooled DNAPL. This conclusion holds regardless of the rate of groundwater pumping.

The high concentrations of dissolved organics in bedrock at the site, past waste disposal practices, and visual observation of a dense materials in a borehole video all support a conclusion that DNAPL entered bedrock at some point in time. As discussed in Kueper (1998), the processes of DNAPL solubilization and matrix diffusion will be a potentially significant limiting influences in restoring groundwater both within the bedrock potential DNAPL zone.

6.5.9 Waterflooding

Waterflooding refers to the physical displacement of DNAPL in response to groundwater pumping. Imposing a hydraulic gradient across residual and pooled DNAPL will increase the capillary pressure at the leading edge of the DNAPL distribution (downstream end) relative to the trailing edge (upstream end), thereby imparting a hydraulic driving force. Waterflooding has been implemented as a secondary oil recovery technology for several decades in the petroleum industry (Lake, 1989). For such applications, however, the objective is to recover an incremental amount of the oil in place, not complete recovery of the oil (Kueper, October 1998).

An analysis of waterflooding to remove residual DNAPL has been performed for similar site conditions to those at the Rodale site (BBL, 1995). Similarly, it is highly unlikely that residual DNAPL can be removed from the Rodale site using waterflooding technology. This conclusion is based on the analysis which was relatively insensitive to the value of intrinsic permeability assigned.

In addition to the removal of residual DNAPL, waterflooding can be considered for the removal of pooled DNAPL. At sites where large, well-defined pools of DNAPL are present, the implementation of a waterflood can be considered to reduce saturations in the pool towards residual levels, thereby eliminating the risk of having the pool mobilized in the future (Kueper, October 1998). Based on this requirement, it can be concluded that water flooding is not a suitable DNAPL zone restoration technology. Although the site may contain small to moderate sized pools of DNAPL, no large and well-defined DNAPL pools have been identified.

6.5.10 Steam Flooding

The use of steam flooding to displace DNAPL in porous media has been suggested as a potential remediation technology in recognition of the fact that many components of DNAPL may have boiling points less than approximately 100 C. To date there have been no full-scale implementations of steam flooding which have resulted in meeting typical concentration based clean-up goals for groundwater. However, the technology is currently receiving more attention than it has in recent years as evidenced by several recent publications (Kueper, October 1998).

If steam is brought into contact with DNAPL composed of chemicals with boiling points less than 100 C, rapid vaporization will occur. The vaporized DNAPL components will travel towards the steam front in the vapor phase where they will condense to form a mobile 'DNAPL bank'. This bank will increase in size as the steam front progresses through the DNAPL zone, leading to a build-up of capillary pressure at the base. It is clear that a geological horizon impermeable to DNAPL must exist beneath the zone to be steam-flooded in order to prevent vertical mobilization of the DNAPL bank (Kueper, October 1998). At the Rodale site, the absence of an impermeable geologic horizon beneath the DNAPL prevents the application of steam flooding because of the high risk of mobilizing DNAPL further into bedrock.

In addition to the problem of vertical DNAPL mobilization in response to increasing capillary pressures in the DNAPL bank, it must be noted that it may be difficult to ensure that injected steam will be brought into contact with all residual and pooled DNAPL. In an unconfined aquifer such as at Rodale, the injected steam will quickly travel upwards into the unsaturated, zone. Steam floods are best suited to confined aquifers where a capillary barrier to the buoyant steam exists above the contaminated zone. Even if the steam can be manipulated to remain in the saturated zone, gravity over-ride and the complicating effect of heterogeneity will result in poor contact between steam and pooled DNAPL located at the base of the zone to be steam flooded. The same issue applies to bedrock (Kueper, October 1998).

It can be concluded on the basis of the above discussion that steam flooding is currently not an appropriate technology for DNAPL removal at the Rodale site. The primary reason for this is the fact that geological conditions exist through which DNAPL may be further mobilized downwards into bedrock, resulting in a more extensive DNAPL distribution. It is also apparent from a consideration of boiling points and the presence of porous and fractured media heterogeneity, that steam flooding would need to be operated as a flushing technology, subject to long tailing towards clean-up levels.

6.5.11 Oxidant Flooding

Oxidant flooding is beginning to receive attention as a technology for the removal of contaminants from sites impacted by organic compounds. A variety of oxidants can be utilized to oxidize organics in-situ below the water table, including potassium permanganate and hydrogen peroxide. The oxidant acts on the aqueous phase form of the contaminant, not directly on DNAPL or LNAPL phases. The injection of oxidants into a DNAPL source zone will enhance the rate of DNAPL dissolution, however, by removing aqueous phase contaminants from the vicinity of DNAPL, thereby increasing the rate of contaminant mass transfer from DNAPL to groundwater.

The CleanOX^R process involves the injection of hydrogen peroxide and a variety of proprietary chemicals into the aquifer. The hydrogen peroxide reacts with ferrous ions (present in the proprietary chemicals) to produce a hydroxyl radical in an acidified aqueous medium. The resulting hydroxyl free radical is a powerful oxidizer which progressively reacts with organic contaminants through a series of oxidation reactions. The organic compounds are oxidized sequentially to progressively less complex, smaller molecules, ultimately producing carbon dioxide and water.

Potassium permanganate oxidation works on the same principle as the CleanOX^R process in that organic compounds are sequentially oxidized to smaller molecules. Both the CleanOX^R process and the use of potassium permanganate are only applicable to certain organic compounds. Both oxidation processes oxidize not only the target organic contaminant, but other oxidizable species such as dissolved organic carbon, and organic carbon present on aquifer solids. This increases the amount of oxidant that must be utilized relative to the amount required to destroy the organic contaminant alone.

To date, there have been no full-scale implementations of oxidant flooding which have resulted in regulatory closure at a site (Kueper, October 1998). The success of oxidant flooding in remediating a DNAPL site is dependent in large part on the ability to deliver the injected chemical solution to the target zones of DNAPL. As with any chemical flooding technology, porous and fractured media heterogeneity will limit the effectiveness of oxidant flooding, and is expected to result only in partial mass removal. Because of the uncertainties currently surrounding the effectiveness of oxidant flooding, and the lack of demonstrated site clean-ups, it can be concluded that the site cannot be restored to regulated groundwater levels using this technology.

6.5.12 Natural Attenuation

Natural attenuation relies on the ground-water's natural restorative ability through physical, chemical, and biological processes. Attenuative processes include dilution, dispersion, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials. The biodegradative and chemical reactions induce electron transfer with consequent molecular transformation to reduce toxicity, while dilution, dispersion and volatilization are physical processes that also help to reduce the toxicity of affected ground water.

The ability of naturally occurring microbial communities to effectively degrade fuel hydrocarbons has been well documented (Buschek et. al., 1995). More recently, however, it has been established that certain types of microorganisms will, under specific conditions, degrade or transform halogenated compounds such as PCE, TCE, 1,1,1-TCA, and related compounds. Anaerobic processes such as reductive dehalogenation and aerobic processes such as co-metabolism are effective as a bioremedial treatment train for chlorinated ethenes and ethanes when applied in sequential combination. (USEPA, 1995).

Natural attenuation is generally a moderate- to long-term process that may be effective in addressing dissolved-phase constituents in ground water in combination with control of the source of the constituents. However, there is very little evidence to suggest that sufficient remediation of DNAPL source area can occur to significantly reduce the lifespan of DNAPL in the subsurface. Natural attenuation should not be evaluated further as a means of restoring groundwater within the potential DNAPL zone in either overburden or bedrock. However, the application of a monitored natural attenuation approach may be effective in the remediation of ground-water constituents downgradient of the site in conjunction with containment of the Probable DNAPL Zone and, therefore, is evaluated further in the FS.

6.5.13 Conclusion

Several of the above-listed technologies have been demonstrated successfully at full-scale field application for remediation of dissolved-phase VOC plumes, including: hydraulic containment; physical containment; permeable treatment walls; biodegradation; air sparging; pump-and-treat; and natural attenuation. However, these technologies are not effective at remediating DNAPL source zones. The technologies listed above that are advanced by some researchers as potentially effective at remediation DNAPL source zones are emerging technologies that are currently being researched at the laboratory or pilot scale in the field (e.g., alcohol flooding and cosolvent flushing; surfactant flushing; and oxidant flooding.) In general, pilot-scale (hundreds of square feet) field demonstrations are performed in shallow, relatively homogeneous sand or sand and gravel formations.

The above evaluation indicates that no technology currently exists that can restore ground water to regulatory cleanup requirements within the Probable DNAPL Zone in bedrock at the Rodale site. The primary problem with any flushing-based technology will be the inability to effectively access DNAPL in the subsurface due to geologic heterogeneity, which was well documented in the RI and is discussed in the Hydrogeologic Conceptual Model in Section 5.0 of this TI Evaluation. The overburden and bedrock formations at the site each have hydraulic conductivity values that range over several orders of magnitude, and contain complex networks of discontinuous interconnected relatively permeable lenses, strata, or fractures. In addition, none of the above-listed technologies can effectively access and remediate the VOCs that have already diffused into the bedrock matrix. The diffused mass of VOCs will serve as a source of dissolved VOCs within the bedrock for an extended time period.

Even if removing a significant fraction of the chemical mass, rather than achieving ground-water ARARs, was the primary goal, the likelihood of success at the site would be extremely small. The petroleum industry has been using waterflooding and surfactants as secondary and tertiary methods to remove petroleum for commercial purposes for decades. However, typical removal efficiencies are on the order of 20 to 70 percent.

As noted above, some emerging technologies are promoted in the research community as potential options to remove DNAPL source zones. However, no successful full-scale demonstrations have been reported in the literature. Of the emerging technologies, surfactants and cosolvents have received a substantial amount of attention and research funding (DOD, 1997). As of October 1997, 29 pilot-scale field demonstrations of surfactants/cosolvents had been completed (DOD, 1997). Most of these studies were carried out in homogeneous sand or sand-and-gravel formations, and all except one were performed at depths less than fifty feet below ground surface. The median percent of the initial DNAPL removed by these pilot scale field demonstrations was estimated as 55 percent. Only one of these seventeen studies reported DNAPL removal greater than 90 percent; however, this removal efficiency was estimated using a partitioning tracer test, which likely overestimated the degree of DNAPL removal. Two of the 17 studies performed in sand and gravel aquifers less than 50 feet below grade reported zero percent DNAPL removal. As of October 1997, there had been, at most, one full-scale application of surfactant/cosolvents (USDOD, 1997).

Also, application of an invasive technology with the intent to remove some DNAPL mass and reduce DNAPL mobility could backfire. Any technology requiring flushing of chemicals through the DNAPL zone will modify hydraulic gradients and chemistry, and would create risk of adversely remobilizing DNAPL. Thus, efforts to limit DNAPL mobility exacerbate DNAPL mobility, and could allow DNAPL to migrate further laterally or deeper into the bedrock. In addition to DNAPL mobilization, it must be recognized that surfactants, cosolvents, and alcohols can significantly (by orders of magnitude) increase the aqueous concentrations of the target contaminants, thus increasing the risk of exposure.

An important requirement for an remedial alternative that may be considered for the DNAPL zones at the site will be to minimize the risk of remobilizing DNAPL laterally or vertically into areas where it does not presently exist. This goal can be achieved by restricting hydraulic gradient and chemical changes that could remobilize the DNAPL (e.g., application of surfactants or alcohols).

6.6 Remedial Time frame Analysis

As stated in the TI guidance document (USEPA, September 1993), estimates of the time frame required to achieve ground-water restoration may be considered in TI evaluations. While restoration time frames may be an important consideration in remedy selection, no single time frame can be specified during which restoration must be achieved to be considered technically practicable. However, very long restoration time frames (e.g., longer than 100 years) may be indicative of hydrogeologic or contaminant-related constraints to remediation. While predictions of restoration time frames may be useful in illustrating the effects of such constraints, USEPA will base TI decisions on an overall demonstration of the extent of such physical constraints at a site, not on restoration time frame analyses alone. A further consideration regarding the usefulness of restoration time frame predictions in TI evaluations is the uncertainty inherent in such analyses.

We are not aware of any publications reporting representative mass-removal rates for innovative or emerging technologies with respect to DNAPL sites. Therefore, it is not possible to extrapolate meaningful time remedial time frame estimates for these technologies, were they attempted at the Rodale site. However, three general statements are supported with respect to the VOC mass distribution in the dissolved and sorbed state, and as DNAPL at the site:

- the mass of VOCs in the dissolved in ground-water is likely in the thousands of kilograms;
- the mass of VOCs sorbed to solids is in the tens of thousands of kilograms; and
- the mass of VOCs as DNAPL within the source area is in the hundreds of thousands of kilograms.

There is no reasonable basis to expect that these DNAPL zones can be remediated to ground-water regulatory criteria in any time frame less than hundreds of years.

To provide a basis for evaluating whether the remedial alternatives considered for this site could achieve MCLs within a reasonable timeframe, an analysis has been performed of the timeframe required for the ground-water quality within the fractured bedrock aquifer at this site to achieve MCLs under both pumping and non-pumping conditions. A conservative limitation of the timeframe required for ground-water quality within the aquifer to achieve MCLs would be the timeframe required from the DNAPL present within the source area to be flushed from the system.

The time required to remove the estimated volume of DNAPL present in the source area under a remedial alternative without active ground-water recovery and treatment as been estimated through the application of a DNAPL flushing equation (Feenstra, 1991) and assuming the same source area dimensions and DNAPL Zone characteristics used to estimate the DNAPL mass (including bedrock bulk retention capacity ranging from 1.6×10^{-4} to 6.4×10^{-4}). The estimated timeframe to flush the mass of DNAPL out of the source area is estimated to range from 212 years to 849 years under the remedial scenario without active ground-water recovery and treatment.

The timeframe required to remove the estimated volume of DNAPL present in the source area under a remedial alternative which includes active ground-water recovery and treatment as been conservatively estimated based on the assumption that the average VOC recovery rate achieved by the existing GWTS during the last six months of continuous operation (approximately 250 kg per month) could be maintained throughout the period of operation required to achieve this objective. The same source area dimensions and characteristics used to estimate the DNAPL mass were also assumed for these estimates. The estimated timeframe to flush the mass of DNAPL out of the source area is estimated to range from 592 years to 2370 years under the remedial scenario with active ground-water recovery and treatment.

7. Cost Estimates for Potential Remedial Technologies

This section presents estimated costs for those remedial alternatives that have been evaluated as being potentially applicable for addressing the presence of DNAPL in the overburden and bedrock. The cost estimates presented herein are based on USEPA's publication *Evaluation of Technologies for In-situ Cleanup of DNAPL Contaminated Sites* (USEPA, 1994; DOD 1997). Many of the technologies evaluated are emerging and most are only available on a pilot scale, have not been widely employed, or may include proprietary information, thus the costs presented in USEPA's evaluation may be biased on limited information. A number of the pilot scale demonstrations presented in USEPA's literature have been completed under favorable hydrogeologic conditions, including homogeneous aquifers with pooled DNAPL, which may underestimate the actual cost of remediation for sites with unfavorable geologic condition, such as those that exist at the Rodale site. In addition several of the technologies have only been used in roughly similar applications (i.e., enhanced petroleum recovery) and have not been used in environmental remediation, thus, cost information may not be directly transferable. site specific conditions including depth to water, depth of contamination, subsurface heterogeneity and the presence of fractured bedrock are expected to significantly increase remedial costs. For purposes of this evaluation, the upper cost range presented in USEPA's evaluation has been used to provide a basis for cost comparison.

Table 11 presents a summary of projected remedial cost estimates to attempt to remediate the Probable DNAPL zone at the Rodale site. Cost estimates have been developed for cosolvent soil washing, surfactant soil washing, water flooding, and steam enhanced extraction. It should be recognized that restoration or the Rodale site would require remediation of approximately 830,000 cubic yards of impacted media. The estimated cost range to remediate the Probable DNAPL zone using these technologies is $99,600,000 to $488,040,000.

In comparison, the FS developed implementable remedial alternatives that will provide an effective alternative remedial strategy to provide protection of human health and the environment by providing exposure control, source control and plume remediation. Feasibility Study Alternative GW-3 provides an effective alternative remedial strategy that includes institutional controls, hydraulic containment and ground-water treatment. The estimated cost of this alternative is approximately $4,240,000.

8. Cost Estimates for Proposed Remedial Alternatives

As discussed in the FS, in addition to being protective to human health and the environment, complying with ARARs (unless waived), utilizing permanent remedies, and satisfying a preference for treatment, the NCP requires the consideration of cost. As stated in the USEPA's guidance *The Role of Cost in the Superfund Remedy Selection Process* (USEPA, September 1996) regarding the consideration of cost during the detailed analysis of alternatives and the identification of a preferred alternative "Cost is a critical factor in the process of identifying a preferred remedy. In fact, CERCLA and the NCP require the <u>every</u> remedy selected <u>must</u> be cost effective." Cost estimates for the three remedial alternatives developed for the site are provided in the FS and summarized below. Pursuant to CERCLA guidance these cost estimates are expected to provide an accuracy of +50% to -30%.

Alternative GW-1: No Action

Under this alternative operation of the existing ground-water extraction and treatment system would cease and the site would be allowed to remain in it's existing condition. Since no active remediation will be undertaken under this alternative there are no capital costs associated with this alternative. This alternative does include an annual ground-water monitoring program to monitor ground-water quality. The estimated annual cost of the ground-water monitoring program is $40,000; the present worth of the annual ground-water monitoring program assuming a 30 year duration and a 7% interest rate is $600,000. The total estimated present worth value of the No Action alternative is $600,000.

Alternative GW-2: Natural Attenuation

Under this alternative operation of the existing ground-water extraction and treatment system would cease and the site would be allowed to remain in it's existing condition. On-going natural attenuation processes would continue to address the dissolved phase plume and would be monitored through a semi-annual ground-water monitoring program. This alternative also includes implementing institutional controls to provide exposure control to contaminated ground water. Capital costs associated with this alternative include legal fees associated with developing and implementing the institutional controls; capital costs have been estimated to be $30,000. The estimated annual cost of the ground-water monitoring program is $75,000; the present worth value of the annual ground-water monitoring program, assuming a 30 year duration and a 7% interest rate is approximately $1,117,000. The total estimated present worth value of the Natural Attenuation alternative is $1,150,000.

Alternative GW-3: Ground-Water Extraction with Conventional Treatment and Natural Attenuation

This alternative assumes that the existing ground-water extraction and treatment system would continue to be operated at the site to provide hydraulic control of on-site ground water. In addition institutional controls would be implemented to provide exposure control to contaminated ground water. This alternative relies on natural attenuation to address the severed portion of the plume downgradient of the hydraulic control. As discussed in the FS, one of the existing ground-water extraction wells (MW-4) will be replaced under this alternative to improve the hydraulic capture of the system and a monitoring well couplet will be installed and sampled evaluate the presence of a preferential flow pathway located northwest of the site. Capital costs associated with this alternative include: legal fees associated with the institutional controls; the installation of a replacement extraction well; and the installation and sampling of a new monitoring well couplet. Since the existing treatment system will be used without modification there are no capital costs associated with the ground-water treatment system. The estimated capital cost of this alternative is $90,000. Operation and maintenance costs associated with this alternative include: operation and maintenance costs associated with operating the existing extraction and treatment system (e.g., electricity, influent/effluent monitoring, etc.); and a semi-annual ground-water monitoring program to monitor ground-water quality and the natural attenuation processes. The estimated annual operation and maintenance cost is $270,000; the present worth value of the annual operation and maintenance program, assuming a 30-year duration and a 7% interest rate is $3,350,000. The total estimated present worth value of the Natural Attenuation alternative is $3,440,000.

9. Protectiveness of Proposed Remedial Alternatives

In accordance with the NCP each of the three alternatives retained for the Detailed Analysis of Alternatives was evaluated in terms of it's ability to provide overall protection of human health and the environment. The HHRA concluded that the only unacceptable risk associated with the site is the human exposure (via contact, ingestion, inhalation) to chemicals of concern (CCS) present in on-site ground water (BBL, October 1998). To address this risk an appropriate remedy must provide exposure control for human exposure to on-site ground water. The ecological risk assessment did not identify any ecological risks and concluded that no further ecological assessment activities are warranted in connection with the site. Thus, environmental risks are limited to the further degradation of ground-water quality. The protectiveness of each of the ground-water alternatives considered for the site is summarized below.

Alternative GW-1: No Action

As detailed in the FS, the No Action alternative is comprised of ground-water monitoring. Under this alternative the site will be allowed to remain in it's current condition and the operation of the existing ground-water extraction and treatment system would cease. This alternative does not restrict the potential future use of contamianted ground water, which would provide exposure control, thus may not be protective of human health. Since, no active remediation of the ground water would occur under this alternative, the No Action alternative would not actively address ground-water quality and thus may not be protective of the environment.

Alternative GW-2: Natural Attenuation

This alternative would rely on a *monitored* natural attenuation approach to address the dissolved-phase contaminants of concern (COCs) in conjunction with institutional controls (e.g., deed restrictions) designed to restrict future usage of the site and the contaminated ground water as long as it continues to exceed relevant criteria. A remedial approach relying on natural attenuation would require demonstrations to show that this alternative would provide passive treatment of the contaminants. While the institutional controls could provide effective exposure control and thus be protective of human health, these controls would have to remain in force until monitoring results demonstrate restoration of the aquifer to the appropriate cleanup levels. Although natural attenuation processes would be expected to reduce the dissolved phase constituents at the leading edge of the plume and thus improve ground-water quality, this alternative does not control the source of COCs (i.e., DNAPL). It could not be assumed that this alternative would achieve attainment of ARARs within a reasonable timeframe. Therefore, this alternative provides limited protectiveness of ground-water quality.

Alternative GW-3: Ground-Water Extraction with Conventional Treatment and Natural Attenuation

This alternative includes the continued operation of the existing ground-water extraction and treatment system which is providing hydraulic control (to the extent practicable) and treatment of the on-site ground water. In addition, this alternative includes: institutional controls which are designed to restrict future usage of the site and contaminated ground water as long as it continues to exceed relevant criteria; and natural attenuation which is providing passive treatment of the severed portion of the dissolved phase plume (i.e., that portion of the dissolved phase plume with is downgradient of the hydraulic control). As this remedial approach relies on natural attenuation to address the severed portion of the plume, demonstrations would be required to show that this alternative would provide passive treatment of the contaminants. As with the Natural Attenuation alternative, this alternative also would rely on institutional controls to prohibit the use of ground-water within the off-site plume until this portion of the aquifer is demonstrated to be restored to the appropriate cleanup levels. This would provide exposure control which will provide protection of human health. The hydraulic control component of this alternative addresses the continued off-site migration of dissolved phase constituents, which, in the absence of non-site-related sources, will utilize a monitored natural attenuation approach to ultimately restore the downgradient dissolved phase aquifer; thus this alternative is considered protective of the environment.

10. Summary and Conclusions

A TI determination is appropriate for the Rodale site due to the presence of substantial quantities of DNAPL in the subsurface, the highly heterogeneous nature of the geologic formations at the site, and the influence of bedrock matrix diffusion.

The horizontal and vertical limits of the Probable DNAPL Zone (TI Zone) for which an ARAR waiver has been proposed are illustrated on Figures 9, 14B and 15B. The approximate source area is estimated to be approximately 350 long, 200 feet wide and extends an average of 320 feet into the bedrock aquifer. The estimated volume of the approximate source area is approximately 830,000 cubic yards (cy). VOC mass calculations indicate the estimated total subsurface VOC mass may range up to 647,000 kilograms (kg), with up to 592,000 kg in the form of DNAPLs, and the remainder of the mass is in dissolved, sorbed, or vapor phase.

Detailed hydrogeologic characterization of the overburden and bedrock units, including their structure and hydraulic conductivity, indicate that these units are highly heterogeneous and complex at a small scale. The bedrock matrix porosity represents a significant storage capacity for VOCs that diffuse into the matrix from the fractures, as confirmed by bedrock matrix VOC analysis. Matrix diffusion reduces the migration rate of the bedrock VOC plumes by a factor of approximately 40. However, matrix diffusion will also significantly hinder efforts to restore bedrock ground-water quality. Preliminary matrix diffusion calculations performed by Dr. Kueper, as detailed in Attachment 1, indicate that diffusion of VOCs back out of the bedrock matrix, after the extended period required for the dissolution of DNAPL, may take an additional 30 years, assuming average homogeneous bedrock conditions. The process of matrix diffusion could be expected to require much longer time periods within portions of the bedrock with smaller fracture frequency and\or tighter fracture apertures and could take less time within portions of the bedrock with greater fracture frequency and/or larger fractures. Given the complex nature of the bedrock at this site, these estimates of the potential impact which matrix diffusion may have on overall time required to achieve restoration of the approximate source area could vary by orders of magnitude.

The existing ground-water containment and treatment system has been in operation since September 1996. Over the two years of ground-water extraction and treatment, approximately 21 million gallons have been pumped, while ground-water concentrations of influent pumped by the system are showing approximately asymptotic levels approximately three orders of magnitude above regulatory criteria. These findings are consistent with the large volume of DNAPL contained within the approximate source area. Estimates of the time required to dissolve the volume of DNAPL from the subsurface range from 592 to 2370 years at current GWTS mass-removal rates.

The area over which the proposed ARAR waiver would apply (TI Zone) is limited to the area within which the presence of DNAPL has been demonstrated (Probable DNAPL Zone).

No existing technology is capable of remediating the TI zone at the Rodale site to ground-water ARARs. Some emerging technologies could remove some mass, but they pose unacceptable risks. Technologies focusing on hydraulic removal via pumping with or without reducing DNAPL-water interfacial tension (e.g., surfactants, alcohols, etc.) would pose unacceptable risk that DNAPL would remobilize in unpredictable directions and spread beyond its current boundaries. Technologies focusing on mass removal via solubility enhancement would pose unacceptable exposure-based risk, and would drive more chemical mass into low-permeability zones through molecular diffusion. Any in-situ remedial technology would need thousands of closely spaced pumping, injection, and/or treatment wells, up to 420 feet deep, to attempt to overcome the extreme heterogeneity of the overburden and bedrock formations. Such efforts would require an immense and costly infrastructure, and would pose unacceptable risk of drilling through DNAPL and remobilizing DNAPL deeper into the bedrock. Any ex-situ technology involving excavation would subject excavation workers and the public to inordinate short-term health risks. On balance, it appears that the risks posed by available technologies may far outweigh any limited benefit each may offer.

Minimizing the risk of DNAPL mobilization is an appropriate remedial action objective. The rationale for invoking a TI waiver for the DNAPL Zone is to waive ARAR for which it is technically impracticable based on current technology to achieve (i.e., the MCL for TCE). The DNAPL and geologic characteristics at the site suggest that the DNAPL is currently in a stable distribution, and will remain in that state unless it is disturbed (such as by drilling or because of chemical or hydraulic gradient changes).

The proposed remedial strategy for the TI zone will minimize the potential for DNAPL remobilization. It includes hydraulic containment of the dissolved-phase plumes emanating from the DNAPL zones, and institutional controls to limit exposure-based risk. This remedial strategy will provide exposure control by means of institutional controls, source control by means of hydraulic containment of the TI Zone, and remediation of the dissolved concentrations of COCs in ground water downgradient of the TI Zone through the use of monitored natural attenuation. The remedy will also provide treatment for any extracted ground water. This proposed remedial alternative will be revisited as part of the Five-Year Review Process.

11. References

Blasland, Bouck & Lee, Inc. (BBL), *Remedial Investigation/Feasibility Study Work Plan Addendum at the Rodale Manufacturing Site Emmaus, Pennsylvania*, May 1996.

Blasland, Bouck & Lee, Inc. "Remedial Investigation Report, Rodale Manufacturing Site, Emmaus, Pennsylvania." March 1998.

BBL, Technical Memorandum Recommendation Regarding Installation of MW-5 Cluster, Rodale Manufacturing Site, Emmaus, PA, September 1996.

Brandes, D., 1992. The effect of phase behavior on residual dense nonaqueous phase liquid displacement from porous media my alcohol flooding. Master thesis, Department of Environmental Systems Engineering, Clemson University, South Carolina.

Braun, Duane D. Surficial Geology of the Allentown East 7.5' Quadrangle, Lehigh, Northampton, and Bucks Counties, Pennsylvania. Harrisburg, Pennsylvania: Pennsylvania Geological Survey, 1996.

Cohen R. M. and Mercer J. W., *DNAPL Site Evaluation*. C. K. Smoley, Boca Raton, Florida. 1993.

Commonwealth of Pennsylvania Department of Environmental *Protection*. Pennsylvania's Land Recycling Program Technical Manual, The Land Recycling and Environmental Remediation Standards Act (PA Act 2 of 1995).

Commonwealth of Pennsylvania Department of Environmental Resources. PA #1276, " Preliminary Assessment for Rodale Manufacturing Company, Inc." May 1987.

Drake, A.A., "The Lyon Station - Paulins Kill Nappe -- The Frontal Structure of the Musconetcong Nappe System in Eastern Pennsylvania and New Jersey." U.S. Geological Survey Professional Paper 1023, 1978.

Drake, A.A., "Geologic Map of the Topton Quadrangle, Lehigh and Berks Counties, Pennsylvania." U.S. Geological Survey Map GQ-1607, 1987.

Feenstra, S., Mackay, D.M., and Cherry, J.A. "A Method for Assessing Residual DNAPL Based on Organic Chemical Concentrations in Soil Samples." Ground-Water Monitoring Review, Vol. 11, No. 2, pp. 128-136. November 1991.

Findlay, R.H. and F.C. Dobbs, 1993. Quantitative Description of Microbial Communities Using Lipid Analysis. In Handbook of Methods in Aquatic Microbial Ecology. Ed. Kemp, P.F., 1993.

Freeze, R.A., and J.A. Cherry. *Groundwater*. Prentice-Hall, 604 p., 1979.

Geo-Environmental Consultants, Inc. (GEC), *Site History and Laboratory Results for the Rodale Manufacturing Site, Emmaus, Pennsylvania.* October 23, 1991.

GEC, *Work Plan for a Time-Critical Investigation at the Rodale Manufacturing Site, Emmaus, Pennsylvania.* Apri 25, 1994.

GEC, *Well Survey Evaluation Summary Report for the Rodale Manufacturing Site.* September 28, 1994.

GEC, *Supplement I to the Time-Critical Work Plan for the Rodale Manufacturing Site in Emmaus, Pennsylvania.* February 28, 1995.

GEC, *Work Plan for a Remedial Investigation/Feasibility Study at the Rodale Manufacturing Site, Emmaus, Pennsylvania.* August 31, 1995.

GEC, *Time-Critical Investigation Report for the Rodale Manufacturing Site, Emmaus, Pennsylvania.* October 1995.

GEC, *Limited Investigation Report for the Vera Cruz/Quarry Road Site, Upper Milford Township, Pennsylvania.* May 2, 1996.

Gorelick S. M., Freeze, R. A., Donohue, D., and Keely, J. F. *Groundwater Contamination: Optimal Capture and Containment.* Lewis Publishers, Boca Raton, Florida. 1993.

Guckert, J.B., and D.C. White, 1986. "Phospholipid, Ester-Linked Fatty Acid Analysis in Microbial Ecology." In Perspectives in Microbial Ecology, Proceedings of the Fourth International Symposium on Microbial Ecology. Slovene Society for Microbiology, Ljuljana, 24-29, August 1986.

Harr, M. E. 1962. *Groundwater and Seepage.* McGraw-Hill: New York.

Kochanov, W.E., "Sinkholes and Karst-Related Features of Lehigh County, Pennsylvania." U.S. Geological Survey, 4th Series, Open-File Report 8701, 1989.

Kueper, B.H., Personal Communication with M.J. Gefell, Blasland, Bouck & Lee, Inc., Syracuse, NY: August 1995.

Kueper, B.H., Personal Communication with M.J. Gefell, Blasland, Bouck & Lee, Inc., Syracuse, NY: July 1998.

NUS Corporation, Superfund Division, *Site Inspection of Rodale Manufacturing Company.* TDD No. F3-8812-02, EPA No. PA-1276, November 15, 1989.

Pankow, J.F. and Cherry, J.A. *Dense Chlorinated Solvents and Other DNAPLs in Groundwater.* Waterloo Press, Portland, Oregon. 1996.

Poulsen, M., and Kueper, B.H. *A Field Experiment to Study the Behavior of Tetrachloroethylene in Unsaturated Porous Media.* Environmental Science and Technology, Vol. 26, No. 5, pp. 889-895, 1992.

R.E. Wright Associates, Inc., *Special Groundwater Study of the Middle Delaware River Basin Study Area II.* 1982.

Roy F. Weston, Inc., *Draft Phase II Hydrogeological Investigation of Rodale Manufacturing Site, Emmaus, Pennsylvania.* November 1989.

Shacklette, H.T., and J.G. Boerngen., "Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States." U.S. Geological Survey Professional Paper 1270, 1984.

Sloto, R.A, L.D. Cecil, and L.A. Senior. "Hydrogeology and Ground-Water Flow in the Carbonate Rocks of the Little Lehigh Creek Basin, Lehigh County, Pennsylvania." U.S. Geological Survey Water-Resources Investigations Report 90-4076, 1991.

Square D Company, Correspondence to United States Environmental Protection Agency (USEPA), September 5, 1996.

SNR Company, *Ground Water Monitoring Plan Prepared for Square D Company, Emmaus, Pennsylvania.* March 17, 1989.

United States Department of Defense (USDOD). Technology Practices Manual for Surfactant and Cosolvents. Rice University, Houston, Texas. October 1997.

United States Environmental Protection Agency (USEPA), "Compendium of ERT Air Sampling Procedures." Office of Emergency and Remedial Response, Washington, D.C., May 1992.

USEPA, Office of Water, "Drinking Water Regulations and Health Advisories." EPA-822-B-96-002..

USEPA, "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA." Publication EPA/540/G89/004. Office of Solid Waste and Emergency Response (OSWER) Directive 9355.3-01, October 1988.

USEPA Region III, "Administrative Order on Consent." Docket No. III-92-15-DC, September 1992.

USEPA, "Estimating Potential for Occurrence of DNAPL at Superfund Sites." Office of Emergency and Remedial Response, Publication 9355.4-07FS, January 1992.

USEPA, "Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration." Office of Solid Waste and Emergency Response (OSWER) Directive 9234.2-25, September 1993.

USEPA Memorandum, "Subject: Consistent Implementation of the FY 1993 Guidance on Technical Impracticability of Ground-Water Restoration at Superfund Sites." Office of Solid Waste and Emergency Response (OSWER) Directive 9200.4-14, January 19, 1995.

USEPA Memorandum, "Subject: Superfund Groundwater RODs: Implementing Change This Fiscal Year." Office of Solid Waste and Emergency Response (OSWER) Directive 9200.4-14, July 31, 1995.

U.S. Geological Survey, "Allentown West and Allentown East 7.5 Minute Topographic Quadrangles."

Walton, W.C., "Selected Analytical Methods for Well and Aquifer Evaluation." Illinois State Water Survey, Bulletin 19, 1962.

Waterloo Centre for Groundwater Research (WCGR) Short Course. Dense, Immiscible Phase Liquid Contaminants (DNAPLs) in Porous and Fractured Media. Kitchener, Ontario, Canada. October 7-10, 1991.

White, D.C., 1988. *Validation of Quantitative Analysis for Microbial Biomass, Community Structure, and Metabolic Activity.* Arch. Hydrobiol. Belh. Ergebn. Limnol. Vol. 31: 1-18.

Wood, C.R., H.N. Flippo, J.B. Lescinsky, and J.L. Barker, "Water Resources of Lehigh County, Pennsylvania." Commonwealth of Pennsylvania Department of Environmental Resources Water Resource Report 31, 1972.

Wood, R.A. (Editor), "Weather of U.S. Cities." 5th edition, Gale Research, Detroit, Michigan, 1996.

Zeigler, T. W. 1976. *Determination of Rock Mass Permeability.* Technical Report S-76-2. U. S. Army Engineer Waterways Experiment Station, Vickburg, MS.

Tables

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

LE 1

SUMMARY OF AVAILABLE INFORMATION FOR ON-SITE WELLS EXISTING PRIOR TO FACILITY CLOSURE IN 1986

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

Well No.	Well 1	Well 2	Well 3	Well 4	Well 5
Well Owner/Operator	Rodale Manufacturing	Rodale Manufacturing	Rodale Manufacturing	Square D Company	Rodale Manufacturing
General Location	West central courtyard; east of Well #2	Boiler house, west end of courtyard; west of Well #1; northeast of Well #6	Behind plant in alley, east end of building, outside courtyard; east of Well #4	East courtyard area; northeast of Well #1	West end of courtyard; east of Well #6; west of Well #2 (removed 2/95)
Year Drilled/ Driller	1952 or earlier/ not known	1938/not known	Not known	06/81/ Gill Enterprises	Not known
Well Type	Disposal	Disposal	Disposal	Monitor	Possible Disposal
Method of Installation	Not known	Not known	Not known	Air Hammer/Air Rotary	Not known
Total Drilled Depth	452'	251'	426'	342'	Not known
Present Well Depth	452'	160'	408'	246'	8'
Casing Material	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Not known
Depth of Casing	405'	57.5'	401.5'	195'	Not known
Method of Completion	Open hole production	Open hole production	Slotted section (53 only) and open hole production at depth	Open hole production to depth	Not known
Initial Completion Interval	405' - 452' bgl/47'	57.5' - 251'/193.5'	401.5' - 426'/24.5'	195' - 342'/147'	Not known
Current Completion Interval	405' - 452' bgl/47'	57.5' - 160'/102.5'	401.5' - 408'/6.5'	195' - 246'/51'	Not known
Completion Interval Diameter	6 ¼"	6"	6"	6 ¼" casing, 6" open hole	Not known
Formation Penetrated at Total Depth	Leithsville Limestone	Leithsville Limestone	Leithsville Limestone	Leithsville Limestone	Drift
Type of Disposed Materials	Electroplating wastes, hydraulic cutting oils, TCE and other	Toilet wastes, electroplating wastes, hydraulic cutting oils, TCE and other	Oils, TCE and other solvents, Oakite (sodium phosphate, tribasic cleaner)	Not used for disposal	Details not known; boiler blowdown wastes
Maximum Period of Disposal/# Years	1952 - 1967/ 15 years	1938 - 1967/ 29 years	1938 - 1967/ 29 years	Not used for disposal	Not known/ not known
Depth to Water - 9/93	119.40'	114.02'	117.40'	116.42'	2.65'
Elevation at Top of Water - 9/93	348.28' (AMSL)	352.08' (AMSL)	348.70' (AMSL)	349.66' (AMSL)	460.74' (AMSL)

E 1

SUMMARY OF AVAILABLE INFORMATION FOR ON-SITE WELLS EXISTING PRIOR TO FACILITY CLOSURE IN 1986

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

Well No.	Well 6	Well 7	WW-08	RW-2	RW-3
Well Owner/Operator	Rodale Manufacturing	Square D Company	Square D Company	Square D Company	Square D Company
General Location	Far west end of courtyard	West of Well #3, north of water treatment building, inside former Building C	West end of former Building D, south of RW-2, east of Well #8	West of former Building D; north of Well #5, south of Well #1	Replacement for Well #2
Year Drilled/ Driller	Possibly 1945/ Biery?	12/94/Summit Drilling Company	Not known	1989/Not known	07-08/94/Summit Drilling Company
Well Type	Process make-up water	Monitor	Not known	Potential Recovery/ Monitor	Recovery
Method of Installation	Not known	Air/Bentonite	Not known	302'	Air/Bentonite
Total Drilled Depth	Not known, possibly 330'	130'	Not known	247'	198'
Present Well Depth	247'	130'	0'	247'	198'
Casing Material	Carbon steel	6-inch Steel	Not known	Steel Casing	Galvanized Steel
Depth of Casing	229'	Not known	Not known	8-inch Steel to 101' 6-inch Steel to 247'	55'
Method of Completion	Open hole production	Morie #1 sand pack, Sch. 40 PVC screen	Brick-lined	Open Hole	Morie #1 sand pack, 6" stainless steel screen
Initial Completion Interval	Not known	105 - 130'/25'	Not known	247-302'/55'	123-198/75'
Current Completion Interval	229' - 247'/18'	105 - 130'/25'	Filled with debris	Not completed	123-198/75'
Completion Interval Diameter	6"	2" PVC Screen, borehole diameter not known	6'	Not completed	6" stainless steel screen
Formation Penetrated at Total Depth	Leithsville Limestone	Leithsville Limestone	Overburden	Leithsville Limestone	Leithsville Limestone
Type of Disposed Materials	Not used for disposal	Possible septic disposal well	Not known	Not used for disposal	Not used for disposal
Maximum Period of Disposal/# Years	Not used for disposal	Not used for disposal	Not known	Not used for disposal	Not used for disposal
Depth to Water - 9/93	113.63'	106.55' (on 12/15/94)	37.8'	Not available	105.2' (on 9/7/94)
Elevation at Top of Water - 9/93	349.13' (AMSL)	357.45' (AMSL) (on 12/15/94)	Not known	Not known	357.77 (AMSL) (on 9/7/94)

Notes:

AMSL = Above Mean Sea Level (NGVD of 1929).
TCE = Trichloroethene.
Locations indicated on Figure 2.

Reference:

"Ground Water Monitoring Plan," SNR Company, March 17, 1989 and borehole TV and geophysical survey conducted by GEC in May 1994.

TABLE 2

EXISTING MONITOR WELL CONSTRUCTION DETAILS

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVAULUATION

DETAILS	MW-1	MW-2	MW-3	MW-4
Top of Casing Elevation*	466.84	459.51	458.91	461.52
Total Well Depth (feet below TOC)	138.0	134.0	138.5	136.0
Estimated Screened Interval (feet below TOC)	113 - 138	109 - 134	113.5 - 138.5	111.0 - 136.0
Depth to Groundwater (feet below TOC)	115.61	109.41	109.18	111.40
Groundwater Elevation*	351.23	350.10	349.73	350.12

SOURCE: "Ground Water Monitoring Plan," SNR Company, March 17, 1989

TABLE NOTES:

* - All elevations in feet above mean sea level (AMSL).
All wells are 4 inches in diameter and of PVC construction.
Wells installed November and December 1988 by SNR Company.
TOC elevations surveyed, September and October 1993 by Martin, Bradbury & Griffith, Allentown, PA.
Depth to water and total depth measured by GEC, September 1993.
Well locations are indicated on Figure 2.

TABLE 3

SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUND WATER ON-SITE WELLS

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA TECHNICAL IMPRACTICABILITY EVALUATION

	PA GW STD	USEPA MCL	MW-1 07/24/98	MW-2 07/23/98	MW-3 07/23/98	MW-4 07/23/98	RW-3 07/23/98	Well 1 07/24/98	Well 2 07/21/98	Well 3 07/23/98	Well 4 07/21/98	Well 6 07/21/98
Acetone	3700 G	NL	50 U	8 J	10 U	1000 U	2500 U	10 U	5000 U	10 U	1000 U	10 U
Vinyl Chloride	2 M	2	50 U	10 U	10 U	1000 U	640 J	780 D	1300 U	16	220 J	10 U
1,2-Dichloroethene (total)	70/100*	70/100*	190	10 U	10 U	640 J	12000	74	36000	230 D	6100	15
Trichloroethene	5 M	5	7500 D	17	180	60000 D	180000 D	8 J	330000 D	340 D	41000 D	190
Tetrachloroethene	5 M	5	45 J	10 U	4 J	840 J	1100 J	10 U	1600 U	2 J	140 J	2 J
Toluene	1,000 M	1,000	50 U	10 U	10 U	1000 U	2500 U	14	5000 U	9 J	1000 U	10 U
Ethylbenzene	700 M	700	50 U	10 U	10 U	1000 U	2500 U	19	5000 U	5 J	1000 U	10 U
Xylene (total)	10,000 M	10,000	50 U	10 U	10 U	1000 U	2500 U	100	5000 U	26	1000 U	10 U

Notes:

The following compounds were analyzed for, but were not detected:

1,1-Dichloroethane
Chloroform
1,2-Dichloroethane
1,1,2-Trichloroethane
Chloroethane
Carbon Disulfide
1,1-Dichloroethene
1,1,1-Trichloroethane
Carbon Tetrachloride
Bromodichloromethane
1,2-Dichloropropane
1,1,1-Trichloroethane
cis-1,3-Dichloropropene
Dibromochloromethane
Benzene
trans-1,3-Dichloropropene
Bromoform
4-Methyl-2-Pentanone
2-Hexanone
1,1,2,2-Tetrachloroethane
Chlorobenzene
Styrene
Bromomethane
2-Butanone
Chloromethane

Results are reported in micrograms per liter (ug/L), equivalent to parts per billion (ppb).
D = Compound was analyzed at a secondary dilution.
J = Estimated value, compound was detected but results are below quantitation limit.
U = Not detected above the reported detection limit.
PA GW STD = Pennsylvania Bulletin Vol. 27, No. 33. Environmental Quality Board (Act 2 Standards): Appendix A, Table 1 - Medium Specific Concentrations (MCS) for Organic Regulated Substances in Groundwater, TDS <= 2500, residential criteria.
USEPA MCL = USEPA Drinking Water Maximum Contaminant Levels - Drinking Water Standards and Health Advisories, USEPA Office of Water, EPA-822-B-96-002, October 1996.
NL = Not listed.
70/100* = 70 M ug/L cis-1,2-dichloroethene standard, and 100 M ug/L trans-1,2-dichloroethene standard.
H = Lifetime Health Advisory Level.
M = Maximum Contaminant Level.
(Dup) = Duplicate sample.

AR300849

TABLE 4

SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUND WATER
OFF-SITE MONITORING WELLS

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

	PA GW STD	USEPA MCL	MW-5S 110-135 07/22/98	MW-5D 275-300 07/22/98	MW-6 147-175 07/22/98	MW-7S 115-145 07/23/98	MW-7D 175-200 07/23/98	MW-8S 130-158 07/24/98
Chloromethane	3 H	NL	10 U	10 U	10 U	10 U	10 U	10 U
Acetone	3700 G	NL	7 J	7 J	10 U	10 U	10 U	10 U
cis-1,2,Dichloroethene	70 M	70	10 U	10 U	10 U	10 U	10 U	10 U
1,1-Dichloroethene	7 M	7	10 U	10 U	10 U	10 U	10 U	10 U
1,1-Dichloroethane	27 N	NL	10 U	10 U	10 U	10 U	10 U	10 U
2-Butanone	NL	NL	10 U	10 U	10 U	10 U	10 U	10 U
Chloroform	100 M	80	10 U	1 J	10 U	10 U	10 U	10 U
Carbon Disulfide	1900 N	NL	10 U	10 U	10 U	10 U	10 U	10 U
Carbon Tetrachloride	5 M	5	10 U	10 U	10 U	10 U	10 U	10 U
Trichloroethene	5 M	5	35	2 J	10 U	8 J	10 U	10 U
Tetrachloroethene	5 M	5	10 U	10 U	10 U	10 U	10 U	10 U
Toluene	1000 M	1000	10 U	10 U	10 U	10 U	10 U	10 U

See Notes on Page 2.

AR300850

TABLE 4

SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUND WATER OFF-SITE MONITORING WELLS

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA TECHNICAL IMPRACTICABILITY EVALUATION

	PA GW STD	USEPA MCL	MW-9S 110-135 07/22/98	MW-9D 275-300 07/22/98	MW-10S 110-135 07/21/98	MW-10I 290-315 07/21/98	MW-10D 450-475 07/21/98	MW-11S 110-135 07/21/98	MW-11D 275-300 07/21/98	MW-12S 25-40 07/22/98	MW-12D 120-140 07/22/98
Chloromethane	3 H	NL	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Acetone	3700 G	NL	10 U	10 U	10 U	10 U	74	10 U	12	7 J	6 J
1,2,Dichloroethene (Total)	70 M	70	4 J	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
1,1-Dichloroethene	7 M	7	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
1,1-Dichloroethane	27 N	NL	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
2-Butanone	NL	NL	10 U	10 U	10 U	10 U	6 J	10 U	10 U	10 U	10 U
Chloroform	100 M	80	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Carbon Disulfide	1900 N	NL	10 U	10 U	10 U	10 U	10 U	10 U	16	10 U	10 U
Carbon Tetrachloride	5 M	5	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Trichloroethene	5 M	5	110	21	10 U	2 J	10 U	10 U	2 J	21	10 U
Tetrachloroethene	5 M	5	1 J	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U
Toluene	1000 M	1000	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U	10 U

Notes:

The following compounds were analyzed for, but were not detected:

Bromomethane
Vinyl Chloride
Chloroethane
1,4-Dichlorobenzene
1,2-Dichloroethane
Bromochloromethane
1,1,1-Trichloroethane
Bromodichloromethane
1,2-Dichloropropane
cis-1,3-Dichloropropene
Dibromochloromethane
1,1,2-Trichloroethane
Benzene
trans-1,3-Dichloropropene
Bromoform
4-Methyl-2-Pentanone
2-Hexanone
1,1,2,2-Tetrachloroethane
1,2-Dibromoethane
Chlorobenzene
Ethylbenzene
Styrene
Xylene (total)
1,3-Dichlorobenzene
1,2-Dichlorobenzene
1,2-Dibromo-3-chloropropane

Results are reported in micrograms per liter (ug/L), equivalent to parts per billion (ppb).
D = Compound was analyzed at a secondary dilution.
J = Estimated value, compound was detected but results are below quantitation limit.
U = Not detected above the reported detection limit.
M = Maximum Contaminant Level.
N = Inhalation.
G = Ingestion.
H = Lifetime Health Advisory Level.
PA GW STD = Pennsylvania Bulletin Vol. 27, No. 33. Environmental Quality Board (Act 2 Standards): Appendix A, Table 1 - Medium Specific Concentrations (MSCs) for Organic Regulated Substances in Groundwater, TDS <= 2500, residential criteria.
USEPA MCL = USEPA Drinking Water Maximum Contaminant Levels - Drinking Water Regulations and Health Advisories, USEPA Office of Water, EPA-822-B-96-002,
NL = Not listed.
bgs = Below ground surface.
(Dup) = Duplicate sample.

TABLE 5

SUMMARY OF INORGANIC COMPOUNDS DETECTED IN GROUND WATER
ON-SITE WELLS

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

	PA GW STD	USEPA MCL	MW-1 07/24/98	MW-2 07/21/98	MW-3 07/23/98	MW-4 07/23/98	RW-3 07/23/98
			Filtered	Filtered	Filtered	Filtered	Filtered
Arsenic	50 M	50	5.6 U	2.8 U	5.6 U	2.8 U	2.8 U
Beryllium	4M	4	0.29 B	0.1 U	0.25 U	0.10 U	0.1 U
Chromium	100M	100	2.0 U	0.63 U	2.1 B	0.63 U	0.63 U
Copper	1000 M	1,000S	2.8 B	3.0 B	3.6 B	0.51 U	3.8 B
Lead	5 M	15*	1.9 U	1.1 U	1.9 U	1.1 U	1.1 U
Manganese	50 SMCL	50S*	296	20.1	12.7 B	67.8	965

	PA GW STD	USEPA MCL	Well 1 07/24/98	Well 2 07/21/98	Well 3 07/23/98	Well 4 07/21/98	Well 6 07/21/98
			Filtered	Filtered	Filtered	Filtered	Filtered
Arsenic	50 M	50	5.6 U	5.9 B	2.8 U	2.8 U	2.8 U
Beryllium	4M	4	0.25 U	0.1 U	0.1 U	0.1 U	0.1 U
Chromium	100M	100	2.0 U	1.2 B	0.63 U	0.63 U	0.63 U
Copper	1000 M	1,000S	1.8 U	0.51 U	7.7 B	0.51 U	0.51 U
Lead	5 M	15*	1.9 U	1.1 U	1.4 B	1.1 U	1.5 B
Manganese	50 SMCL	50S*	739	1030	155	979	33.1

Notes:

Results are reported in micrograms per liter (ug/L) equivalent to parts per billion (ppb).
J = Estimated value, compound was detected but results are below quantitation limit.
U = Not detected above the reported detection limit.
R = Data rejected based on data validation due to concentrations detected in the filtered rinse blank.
B = Possible/probable laboratory contamination, analyte was found in method blank as well as sample.
M = Maximum Contaminant Level.
SMCL = Secondary Maximum Contaminant Level.
PA GW STD = Pennsylvania Bulletin Vol. 27, No. 33. Environmental Quality Board (Act 2 Standards): Appendix A, Table 1 - Medium Specific Concentrations (MSCs)for Organic Regulated Substances in Groundwater, TDS <= 2500, residential criteria.
USEPA MCL = USEPA Drinking Water Maximum Contaminant Levels - Drinking Water Regulations and Health Advisories, USEPA Office of Water, EPA-822-B-96-002,October 1996.
S = Secondary MCL based on aesthetics.
* = Action level, not standard.
(Dup) = Duplicate sample.

TABLE 6

SUMMARY OF INORGANIC COMPOUNDS DETECTED IN GROUND WATER
OFF-SITE WELLS

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

	PA GW STD	USEPA MCL	MW-5S 07/22/98	MW-5D 07/22/98	MW-6 07/22/98	MW-9S 07/22/98	MW-9D 07/22/98	MW-10S 07/21/98
			Filtered	Filtered	Filtered	Filtered	Filtered	Filtered
Arsenic	50 M	50	2.8 U	2.8 U	2.8 U	2.8 U	3.4 B	2.8 U
Beryllium	4M	4	0.37 B	0.1 U	0.1 U	0.1 U	0.1 U	0.41 B
Chromium	100M	100	0.64 B	1.3 B	0.63 U	0.63 U	1.7 B	1.7 B
Copper	1000 M	1,000S	0.51 U	0.51 U	0.51 U	0.51 U	0.6 B	4.3 B
Lead	5 M	15*	1.1 U	1.1 U	1.1 U	1.1 U	1.1 U	1.5 B
Manganese	50 SMCL	50S*	10.4 B	0.09 U	10.2 B	0.74 B	0.85 B	983

	PA GW STD	USEPA MCL	MW-10I 07/21/98	MW-10D 07/21/98	MW-11S 07/21/98	MW-11D 07/21/98	MW-12S 07/22/98	MW-12D 07/22/98
			Filtered	Filtered	Filtered	Filtered	Filtered	Filtered
Arsenic	50 M	50	2.8 U	10.7	2.8 U	2.8 U	2.8 U	2.8 U
Beryllium	4M	4	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Chromium	100M	100	1.1 B	2.6 B	0.63 U	0.63 U	0.95 B	0.63 U
Copper	1000 M	1,000S	0.51 U	0.51 U	1.1 B	0.51 U	5.8 B	2.1 B
Lead	5 M	15*	1.1 U	1.1 U	1.1 U	1.1 U	1.1 U	1.1 U
Manganese	50 SMCL	50S*	0.13 B	0.14 B	20	0.09 U	54.6	12.8 B

<u>Notes:</u>

Results are reported in micrograms per liter (ug/L) equivalent to parts per billion (ppb).
J = Estimated value, compound was detected but results are below quantitation limit.
U = Not detected above the reported detection limit.
R = Data rejected based on data validation due to concentrations detected in the filtered rinse blank.
B = Possible/probable laboratory contamination, analyte was found in method blank as well as sample.
M = Maximum Contaminant Level.
SMCL = Secondary Maximum Contaminant Level.
PA GW STD = Pennsylvania Bulletin Vol. 27, No. 33. Environmental Quality Board (Act 2 Standards): Appendix A, Table 1 - Medium Specific Concentrations (MSCs)for Organic Regulated Substances in Groundwater, TDS <= 2500, residential criteria.
USEPA MCL = USEPA Drinking Water Maximum Contaminant Levels - Drinking Water Regulations and Health Advisories, USEPA Office of Water, EPA-822-B-96-002,October 1996.
S = Secondary MCL based on aesthetics.
* = Action level, not standard.
(Dup) = Duplicate sample.

TABLE 7

SUMMARY OF GROUND-WATER ELEVATION DATA

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

Well	Referenc Elevation (ft AMSL)	Total Depth (ft. bgs)	Depth to Water (feet)	Water Elevation (ft AMSL)	Depth to Water (feet)	Water Elevation (ft AMSL)	Depth to Water (feet)	Water Elevation (ft AMSL)	Depth to Water (feet)	Water Elevation (ft AMSL)	Depth to Water (feet)	Water Elevation (ft AMSL)	Depth to Water (feet)	Water Elevation (ft AMSL)
			08/19/96		10/18/96		01/07/97		03/11/97		10/01/97		07/20/98	
MW-1	466.84	138.00	111.21	355.63	112.65	354.19	106.42	360.42	106.62	360.22	115.85	350.99	114.20	352.64
MW-2	459.51	134	104.84	354.67	106.45	353.06	100.37	359.14	100.26	359.25	NA	NA	109.56	349.95
MW-3	458.91	138.5	104.62	354.29	106.26	352.65	99.97	358.94	100.11	358.80	110.60	348.31	109.55	349.36
MW-4	459.80	136	104.58	355.22	106.52	353.28	100.61	359.19	100.76	359.04	110.76	349.04	109.61	350.19
MW-5D	438.09	304	NA	NA	87.24	350.85	79.67	358.42	80.44	357.65	88.34	349.75	86.20	351.89
MW-5S	438.10	140	NA	NA	85.83	352.27	78.81	359.29	79.26	358.84	87.03	351.07	84.95	353.15
MW-6	489.81	175	137.26	352.55	138.93	350.88	131.33	358.48	131.52	358.29	139.99	349.82	137.89	351.92
MW-7D	467.38	200	112.87	354.51	114.27	353.11	108.13	359.25	107.88	359.50	115.05	352.33	114.11	353.27
MW-7S	467.80	145	110.46	357.34	111.88	355.92	107.24	360.56	105.84	361.96	111.85	355.95	111.64	356.16
MW-8D	453.08	210	100.50	352.58	102.16	350.92	94.61	358.47	95.42	357.66	103.34	349.74	101.20	351.88
MW-8S	453.73	158	100.99	352.74	102.72	351.01	95.12	358.61	95.93	357.80	103.85	349.88	101.65	352.08
MW-9D	415.30	300	60.10	355.20	61.43	353.87	55.56	359.74	56.05	359.25	62.58	352.72	61.14	354.16
MW-9S	415.25	135	58.23	357.02	59.46	355.79	54.18	361.07	54.71	360.54	60.62	354.63	59.19	356.06
MW-10D	426.89	475	73.46	353.43	76.06	350.83	68.55	358.34	69.41	357.48	76.30	350.59	75.30	351.59
MW-10I	427.14	315	74.25	352.89	76.23	350.91	68.62	358.52	69.43	357.71	77.34	349.80	75.13	352.01
MW-10S	427.13	135	69.88	357.25	71.70	355.43	66.08	361.05	66.15	360.98	72.85	354.28	71.19	355.94
MW-11D	444.48	300	91.64	352.84	93.64	350.84	86.05	358.43	86.81	357.67	94.73	349.75	92.57	351.91
MW-11S	444.35	135	86.72	357.63	88.45	355.90	83.50	360.85	82.28	362.07	89.03	355.32	88.00	356.35
MW-12D	494.20	140	73.67	420.53	79.78	414.42	67.69	426.51	66.60	427.60	80.91	413.29	76.53	417.67
MW-12S	494.48	40	24.00	470.48	25.54	468.94	18.82	475.66	19.98	474.50	27.63	466.85	24.50	469.98
PSW-1	422.00	315	75.00	347.00	NA	NA	NA	NA	NA	NA	NA	NA	76.00	346.00
PSW-2	422.00	375	68.00	354.00	NA	NA	NA	NA	NA	NA	NA	NA	72.00	350.00
PSW-3	410.00	526	62.00	348.00	NA	NA	NA	NA	NA	NA	NA	NA	64.66	345.34
PSW-4	462.00	187	121.50	340.50	NA	NA	NA	NA	NA	NA	NA	NA	121.66	340.34
PSW-6	400.00	350	63.00	337.00	NA	NA	NA	NA	NA	NA	NA	NA	74.00	326.00
PSW-7	360.00	400	54.50	305.50	NA	NA	NA	NA	NA	NA	NA	NA	54.66	305.34
RW-3	462.97	198	108.50	354.47	110.62	352.35	103.18	359.79	138.50	324.47	115.25	347.72	NA	NA
WELL 1	467.68	452	115.37	352.31	116.87	350.81	109.25	358.43	110.04	357.64	117.95	349.73	115.85	351.83
WELL 2	466.10	148	110.00	356.10	111.67	354.43	105.40	360.70	109.43	356.67	115.80	350.30	116.69	349.41
WELL 3	462.12	416	109.21	352.91	110.33	351.79	103.47	358.65	105.40	356.72	NA	NA	119.60	342.52
WELL 4	462.45	247	108.52	353.93	109.89	352.56	103.24	359.21	113.05	349.40	138.95	323.50	137.02	325.43

Notes:

AMSL = Above mean sea level. Datum used was NGVD of 1929.
bgs = Below ground surface.
NA = Not available.
Water levels not adjusted for density variations.
MW-2 was inaccessible on 10/1/97.
Well 3 not available due to equipment problems.

TABLE 8

SUMMARY OF AQUIFER CHARACTERIZATION DATA

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

Consultant Test Type Dates	Data Reduction Method	Well Monitored	Interval Monitored (ft. bgs)	Transmissivity (gpd/ft)	Range of Computed Hydraulic Conductivity (cm/sec)
SNR Company Pumping Test October - November 1988	Theis Pumping Phase	Well 2	57.5 - 160	1,767	3.63E-05 - 1.59E-04
		Well 3	401.5 - 408	1,167	2.41E-05 - 1.05E-04
		Well 6	229 - 247	583	1.18E-05 - 5.24E-05
	Cooper-Jacob's Pumping Phase	Well 2	57.5 - 160	3,054	6.27E-05 - 2.75E-04
		Well 3	401.5 - 408	2,776	5.71E-05 - 2.50E-04
		Well 6	229 - 247	1,544	3.16E-05 - 1.39E-04
	Cooper-Jacob's Recovery Phase	Well 2	57.5 - 160	4,765	9.76E-05 - 4.28E-04
		Well 3	401.5 - 408	5,842	1.20E-04 - 5.25E-04
		Well 6	229 - 247	1,933	3.96E-05 - 1.74E-04
BBL Specific Capacity Testing June - October 1996	Walton's Specific Capacity Reduction	MW-5D	265 - 285	6,300	1.4E-02
		MW-5D	281 - 301	110	2.4E-04
		MW-9D	240 - 260	510	1.2E-03
		MW-9D	260 - 280	480	1.1E-03
		MW-10D	231 - 261	580	9.2E-04
		MW-10D	261 - 291	60	9.5E-05
		MW-10D	307 - 337	12,000	1.9E-02
		MW-10D	330 - 370	82,000	9.7E-02
		MW-10D	358 - 398	120,000	1.4E-01
		MW-10D	398 - 438	9,900	1.2E-02
		MW-10D	448 - 488	85	1.0E-04
		MW-11D	240 - 260	560	1.3E-03
		MW-11D	260 - 280 (a)	590	1.4E-03
		MW-11D	260 - 280 (b)	450	1.1E-03
		MW-11D	280 - 300	3,500	8.2E-03
BBL *Pumping Test* August 1998	Jacob's *Straight-Line* Time Drawdown	Phase I MW-1	113 - 138	5,000	Not calculated
		MW-4	111 - 136	900	
		Well 2	57.5 - 160	300	
		Well 4	195 - 246	3,000	
		RW-3	125 - 198	70	
		Phase II MW-1	113 - 138	3,000	1.59E-03 - 1.06E-03
		MW-4	111 - 136	3,000	1.59E-03 - 1.06E-03
		Well 2	57.5 - 160	900	4.77E-04 - 3.18E-04
		Well 4	195 - 246	9,000	4.77E-03 - 3.18E-03
		RW-3	123 - 198	500	2.65E-04 - 1.77E-04
	Distance Drawdown	Phase II RW-3	111-136	500	2.65E-04 - 1.77E-04

Notes:

ft. bgs = Feet below ground surface.
gpd/ft = Gallons per day per foot.
cm/sec = Centimeters per second.
Hydraulic conductivity data were not calculated for Phase I due to the incomplete duration of the aquifer test during Phase I.

TABLE 9

COST SUMMARY FOR POTENTIAL NAPL TREATMENT TECHNOLOGIES

RODALE MANUFACTURING SITE, EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

Treatment Technology	Applicability	Scale	Efficiency	Unit Cost $/CY	Probable NAPL Zone	
					Volume CY	Cost $
Cosolvent Soil Washing[1] (low conc. Alcohol Flooding)	Dissolved and separate phase	Laboratory	Intermediate	65-588	830,000	$488,040,000
Surfactant Soil Washing[1]	Dissolved and separate phase	Pilot	Intermediate/High	65-588	830,000	$488,040,000
Water Flooding[2]	Dissolved and separate phase	Full	Low/Intermediate	50-100	830,000	$83,000,000
Steam Enhanced Extraction[2]	Dissolved and separate phase	Pilot	High	50-125	830,000	$99,600,000

Notes:

[1] Cosolvent and surfactant soil washing are in-situ treatment technologies. An average Unit cost of $270/CY, based on DOD (1997), has been used.

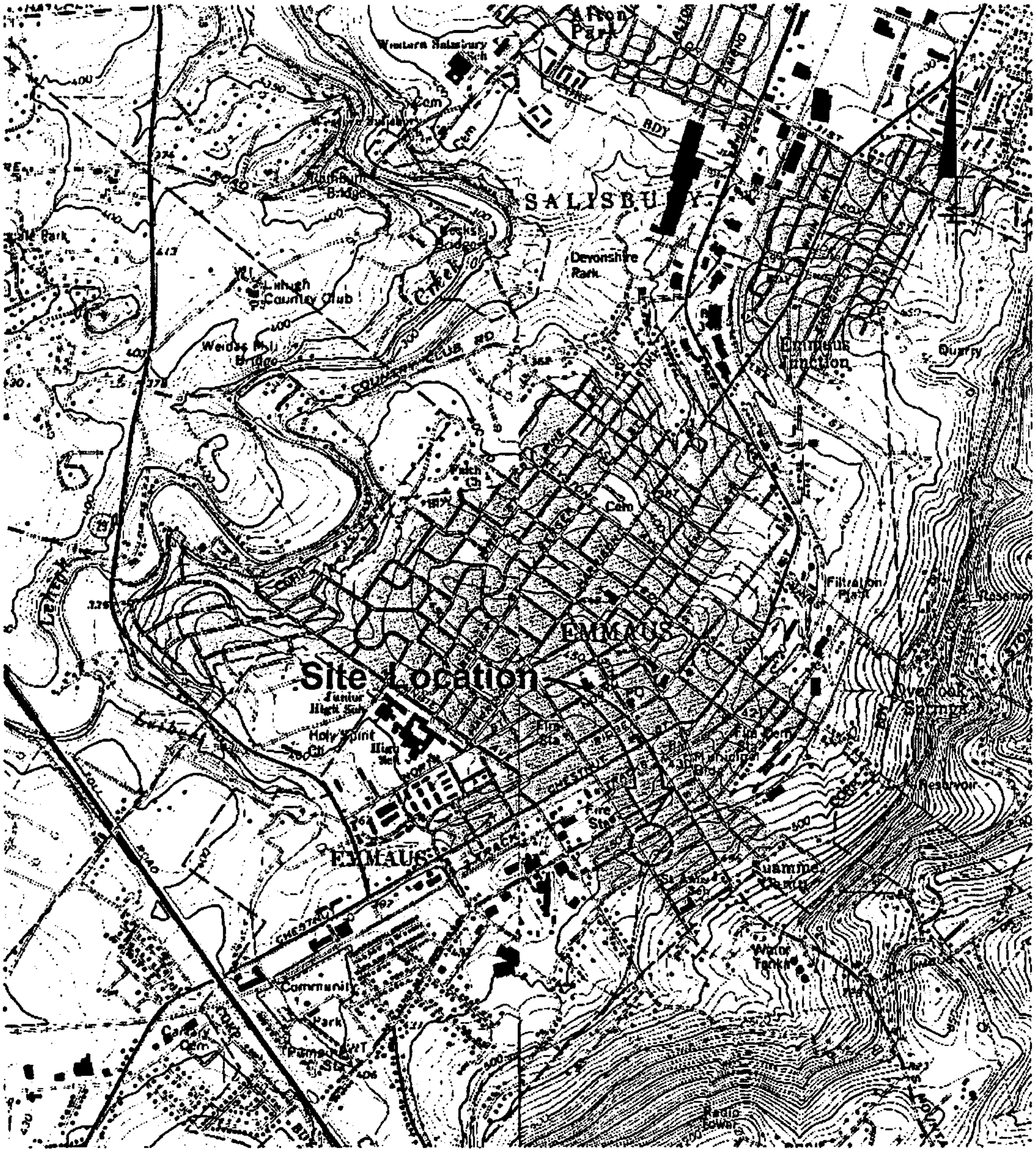
[2] Data presented is a modified version of information presented in USEPA, "Evaluation of Technologies for In-Situ Cleanup of DNAPL Contaminated Sites", by Grubb, D.G., and Sitar, N., Cooperative Agreement No. CR-818956, Processes and Systems Research Division, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development , EPA/600/R-94/120, August, 1994. Unit costs are from referenced document. For the purpose of this evaluation we have presented costs based on the high end of unit cost range to account for the complexity encountered when applying these technologies under Site conditions.

[3] Impacted zone volumes calculated based on the following assumption:

Probable NAPL zone dimensions 350 ft L, 200 ft W, 320 ft D.

Figures

BLASLAND, BOUCK & LEE, INC.
engineers & scientists



REFERENCE: Base Map Source: USGS 7.5 Min. Topo. Quad., Allentown West, PA. & Allentown East, PA (1964, Photoinspected 1983, Revised 1992).

Scale:

2000' 0 2000'

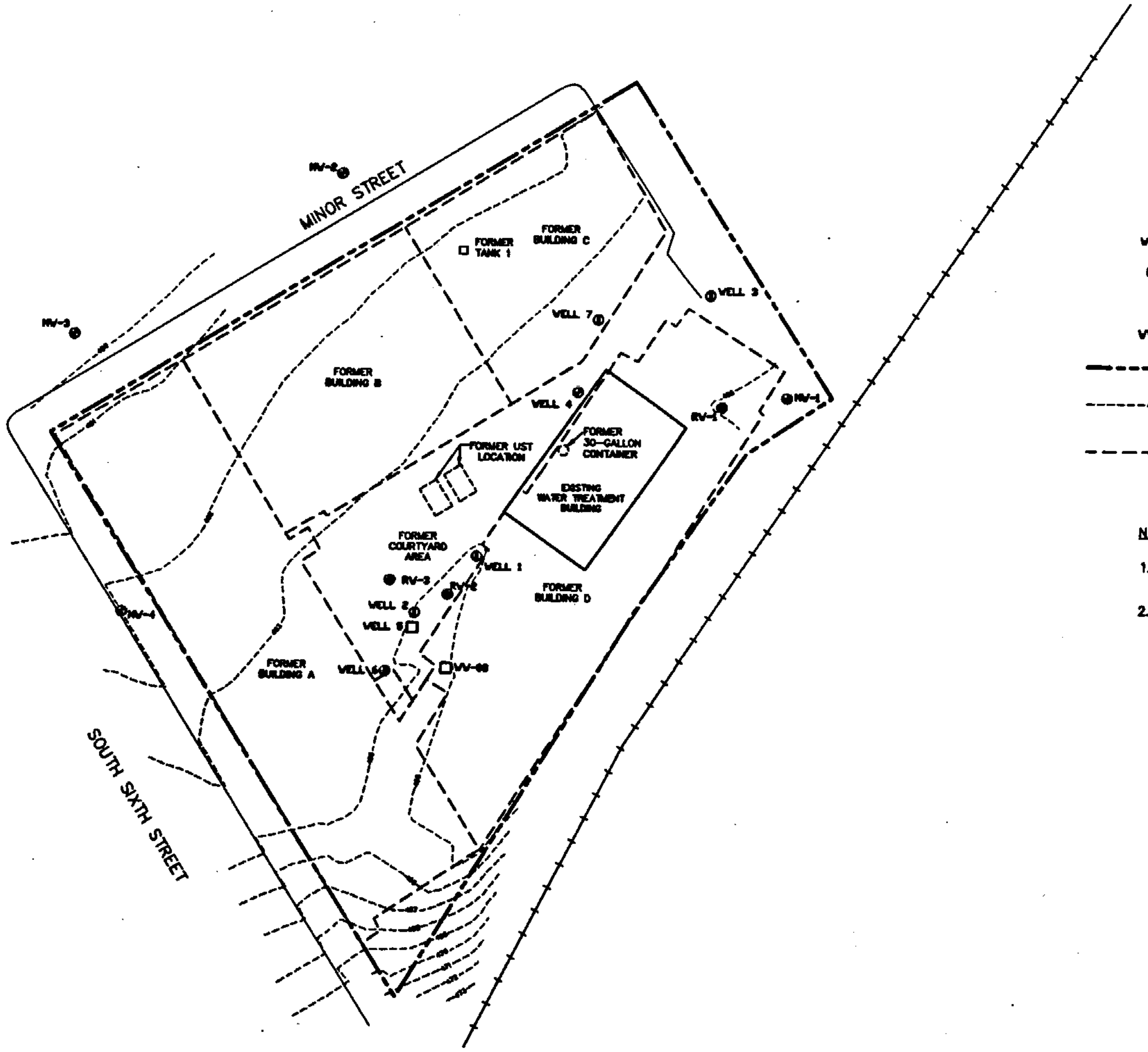
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

SITE LOCATION MAP

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
1

10/96 SYR-D54-DJH, jvm
06461050/06461n03.cdr



LEGEND

WELL 1 ⊕	FORMER DISPOSAL WELL
MW-2 ⊗	GROUND-WATER MONITORING WELL
RV-1 ●	RECOVERY WELL
VV-08 □	CISTERN
▬ ‒ ‒ ▬	PROPERTY BOUNDARY
- - - - 405 - - - -	GROUND-SURFACE ELEVATION CONTOUR IN FEET ABOVE MEAN SEA LEVEL
— — — —	FOOTPRINT OF FORMER BUILDING

NOTES:

1. BASE MAP DIGITIZED FROM SITE PLAN, PROVIDED IN RI/FS WORK PLAN (GEC, 1995).
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLE LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.

SCALE:
0 40' 80'

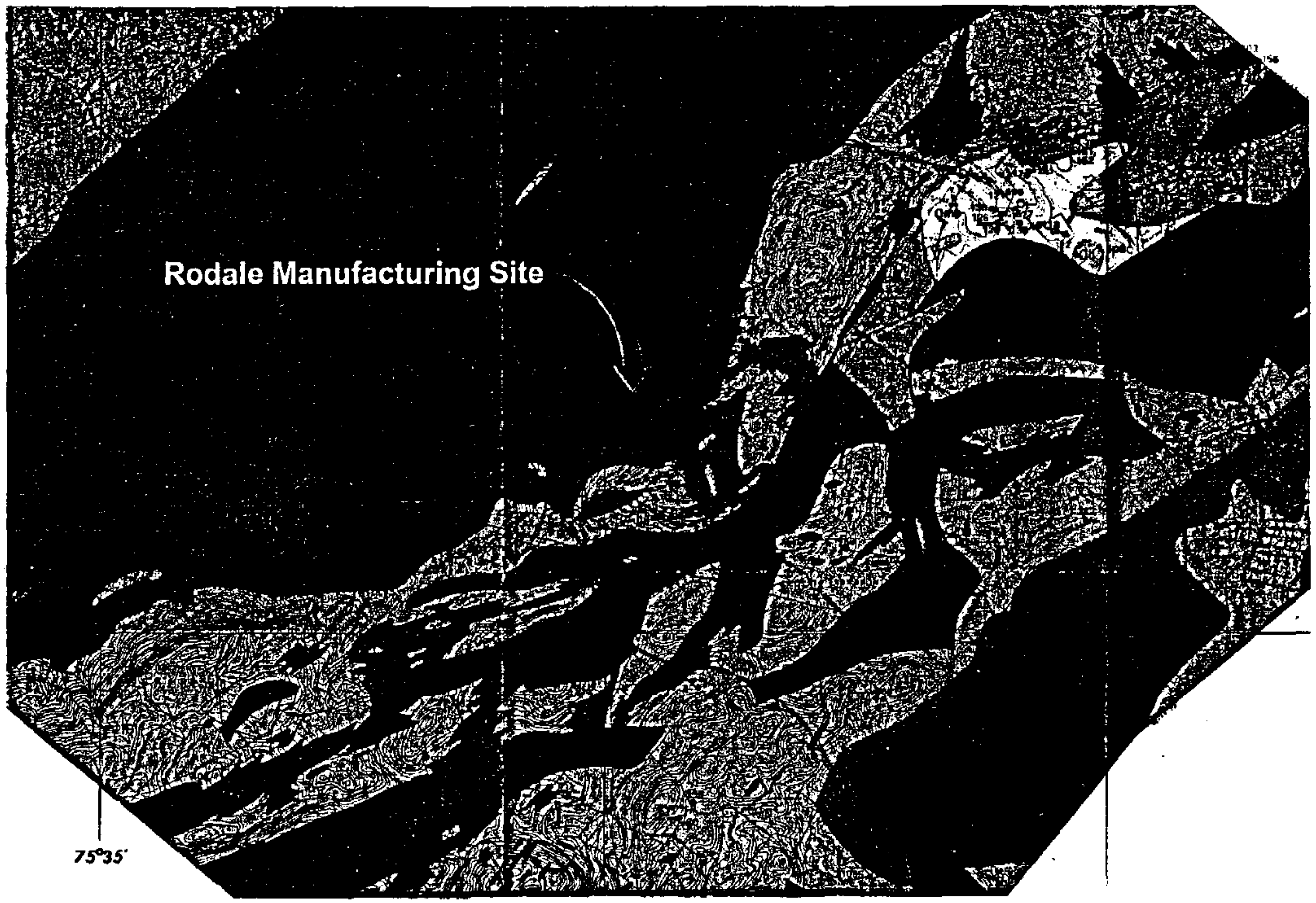
L: ON=*, OFF=REF
P: STD-PCP/BZ0L
2/16/99 SYR-54-GMS
[illegible]/[illegible].DWG

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

SITE PLAN/WELL LOCATION MAP

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 2



NOTE:

1. Modified from Plate 2, C.R. Wood et al. (1972), Water Resources of Lehigh County, Pennsylvania: Commonwealth of Pennsylvania Department of Environmental Resources, Water Resource Report 31.

5000 0 5000 ft

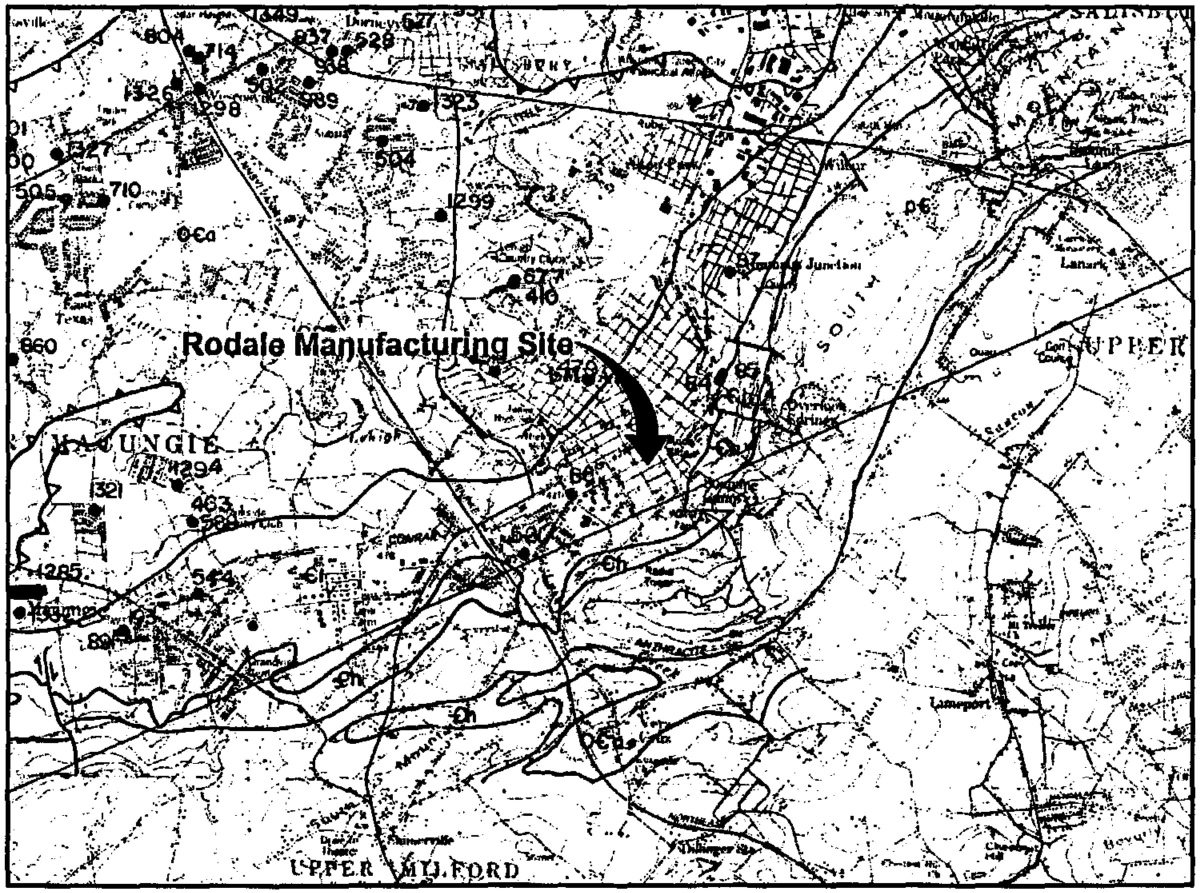
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

GEOLOGIC MAP IN THE VICINITY OF THE RODALE MANUFACTURING SITE

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
3

07/97 SYR-D64-DJH
06451050/06451g02.cdr



NOTE:

1. Modified from Plate 1, R.A. Sloto et al. (1991), Hydrogeology and Ground-Water Flow in the Carbonate Rocks of the Little Lehigh Creek Basin, Lehigh County, Pennsylvania: U.S. Geological Survey Water-Resource Investigation Report 90-4076.

4000 0 4000 ft

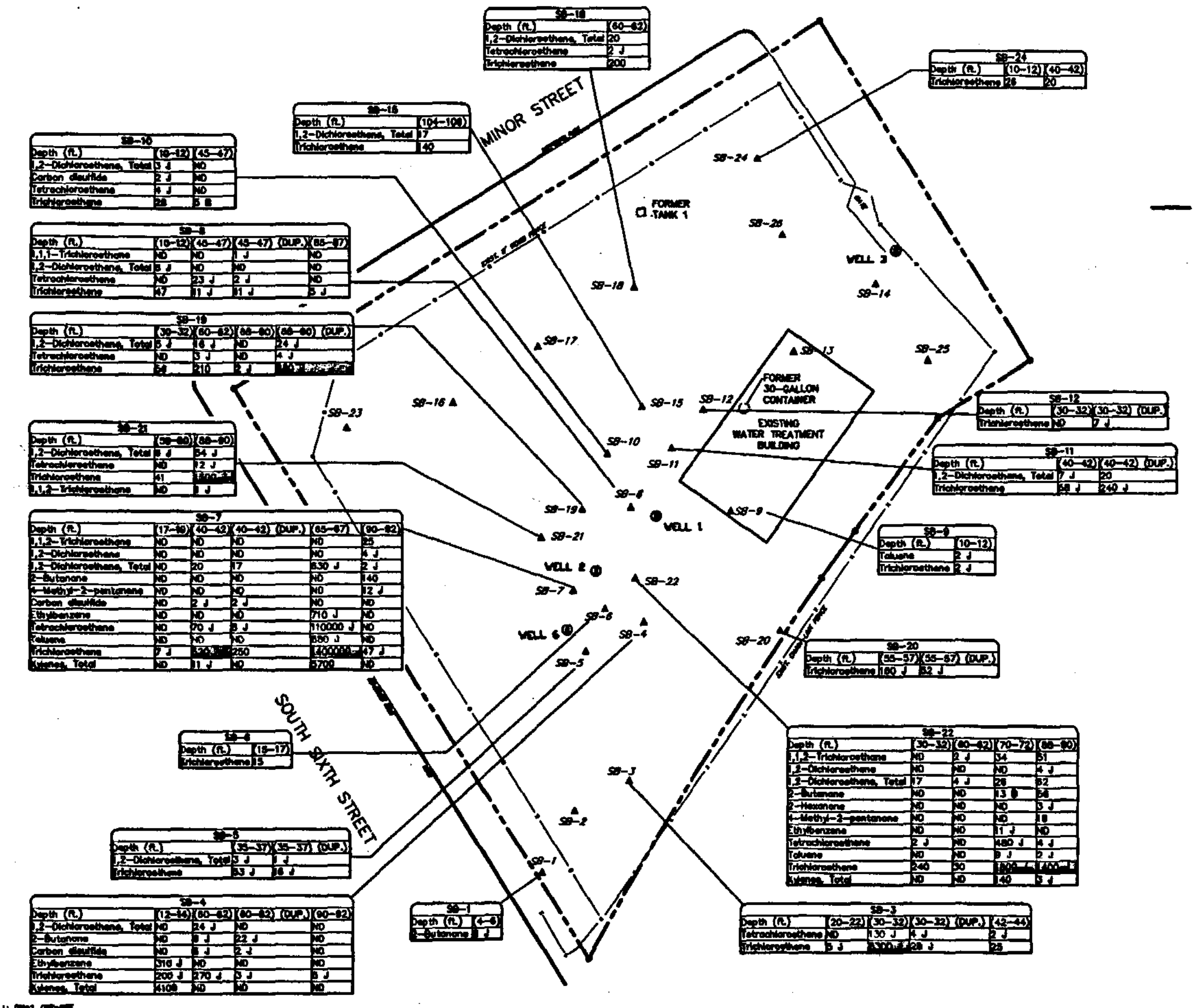
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

GEOLOGY AND LOCATION OF SELECTED WELLS AND SPRINGS

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4

07/97 SYR-D54-DJH
86481050/06461g01.cdr



SB-18

Depth (ft.)	(60-62)
1,2-Dichloroethene, Total	20
Tetrachloroethene	2 J
Trichloroethene	200

SB-16

Depth (ft.)	(104-106)
1,2-Dichloroethene, Total	17
Trichloroethene	140

SB-24

Depth (ft.)	(10-12)	(40-42)
Trichloroethene	26	20

SB-10

Depth (ft.)	(10-12)	(45-47)
1,2-Dichloroethene, Total	3 J	ND
Carbon disulfide	2 J	ND
Tetrachloroethene	4 J	ND
Trichloroethene	28	5 B

SB-8

Depth (ft.)	(10-12)	(45-47)	(45-47) (DUP.)	(85-87)
1,1,1-Trichloroethane	ND	ND	1 J	ND
1,2-Dichloroethene, Total	5 J	ND	ND	ND
Tetrachloroethene	ND	23 J	2 J	ND
Trichloroethene	47	31 J	31 J	5 J

SB-19

Depth (ft.)	(30-32)	(60-62)	(88-90)	(88-90) (DUP.)
1,2-Dichloroethene, Total	5 J	16 J	ND	24 J
Tetrachloroethene	ND	3 J	ND	4 J
Trichloroethene	58	210	2 J	[illegible]

SB-21

Depth (ft.)	(58-60)	(88-90)
1,2-Dichloroethene, Total	8 J	54 J
Tetrachloroethene	ND	12 J
Trichloroethene	41	1400 J
1,1,2-Trichloroethane	ND	3 J

SB-7

Depth (ft.)	(17-19)	(40-42)	(40-42) (DUP.)	(65-67)	(90-92)
1,1,2-Trichloroethane	ND	ND	ND	ND	25
1,2-Dichloroethane	ND	ND	ND	ND	4 J
1,2-Dichloroethene, Total	ND	20	17	830 J	2 J
2-Butanone	ND	ND	ND	ND	140
4-Methyl-2-pentanone	ND	ND	ND	ND	12 J
Carbon disulfide	ND	2 J	2 J	ND	ND
Ethylbenzene	ND	ND	ND	710 J	ND
Tetrachloroethene	ND	70 J	8 J	110000 J	ND
Toluene	ND	ND	ND	880 J	ND
Trichloroethene	7 J	520 J	250	1400000 J	47 J
Xylenes, Total	ND	11 J	ND	5700	ND

SB-6

Depth (ft.)	(15-17)
Trichloroethene	15

SB-5

Depth (ft.)	(35-37)	(35-37) (DUP.)
1,2-Dichloroethene, Total	3 J	1 J
Trichloroethene	53 J	16 J

SB-4

Depth (ft.)	(12-14)	(80-82)	(80-82) (DUP.)	(90-92)
1,2-Dichloroethene, Total	ND	24 J	ND	ND
2-Butanone	ND	8 J	22 J	ND
Carbon disulfide	ND	6 J	2 J	ND
Ethylbenzene	310 J	ND	ND	ND
Trichloroethene	200 J	270 J	3 J	6 J
Xylenes, Total	4100	ND	ND	ND

SB-1

Depth (ft.)	(4-6)
2-Butanone	3 J

SB-12

Depth (ft.)	(30-32)	(30-32) (DUP.)
Trichloroethene	ND	7 J

SB-11

Depth (ft.)	(40-42)	(40-42) (DUP.)
1,2-Dichloroethene, Total	7 J	20
Trichloroethene	58 J	240 J

SB-9

Depth (ft.)	(10-12)
Toluene	2 J
Trichloroethene	2 J

SB-20

Depth (ft.)	(55-57)	(55-57) (DUP.)
Trichloroethene	180 J	32 J

SB-22

Depth (ft.)	(30-32)	(60-62)	(70-72)	(88-90)
1,1,2-Trichloroethane	ND	2 J	34	51
1,2-Dichloroethane	ND	ND	ND	4 J
1,2-Dichloroethene, Total	17	4 J	26	62
2-Butanone	ND	ND	13 B	56
2-Hexanone	ND	ND	ND	3 J
4-Methyl-2-pentanone	ND	ND	ND	18
Ethylbenzene	ND	ND	11 J	ND
Tetrachloroethene	2 J	ND	480 J	4 J
Toluene	ND	ND	9 J	2 J
Trichloroethene	240	30	1800 J	1400 J
Xylenes, Total	ND	ND	140	3 J

SB-3

Depth (ft.)	(20-22)	(30-32)	(30-32) (DUP.)	(42-44)
Tetrachloroethene	ND	130 J	4 J	2 J
Trichloroethene	5 J	3300 J	28 J	25

LEGEND

— — —	PROPERTY BOUNDARY
◉ WELL 1	FORMER DISPOSAL WELL
▲ SB-26	SUBSURFACE SAMPLING LOCATION
J	= THE COMPOUND WAS POSITIVELY IDENTIFIED; HOWEVER THE ASSOCIATED NUMERICAL VALUE IS AN ESTIMATED CONCENTRATION ONLY
B	= THE COMPOUND HAS BEEN FOUND IN THE SAMPLE AS WELL AS ITS ASSOCIATED BLANK, ITS PRESENCE IN THE SAMPLE MAY BE SUSPECT.
ND	= NOT DETECTED
(DUP.)	= DUPLICATE SAMPLE

NOTES:

1. BASE MAP MODIFIED FROM BARRY ISETT AND ASSOCIATES, P.C. SURVEY, DATED 10/31/94.
2. ALL TOTAL SOIL CONCENTRATIONS ARE REPORTED AS ug/kg (ppb).
3. SAMPLES COLLECTED BY GEC 8/9/94 THROUGH 9/30/94, AND 3/11/96 THROUGH 3/14/96 AND ANALYZED BY LANCASTER LABORATORIES.
4. B QUALIFIED ACETONE AND METHYLENE CHLORIDE DATA NOT ILLUSTRATED.
5. SHADED CONCENTRATIONS ARE ABOVE THE PA ACT 2 STANDARDS (TCE STANDARD = 500 ug/kg).

SCALE:

40' 0 40'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

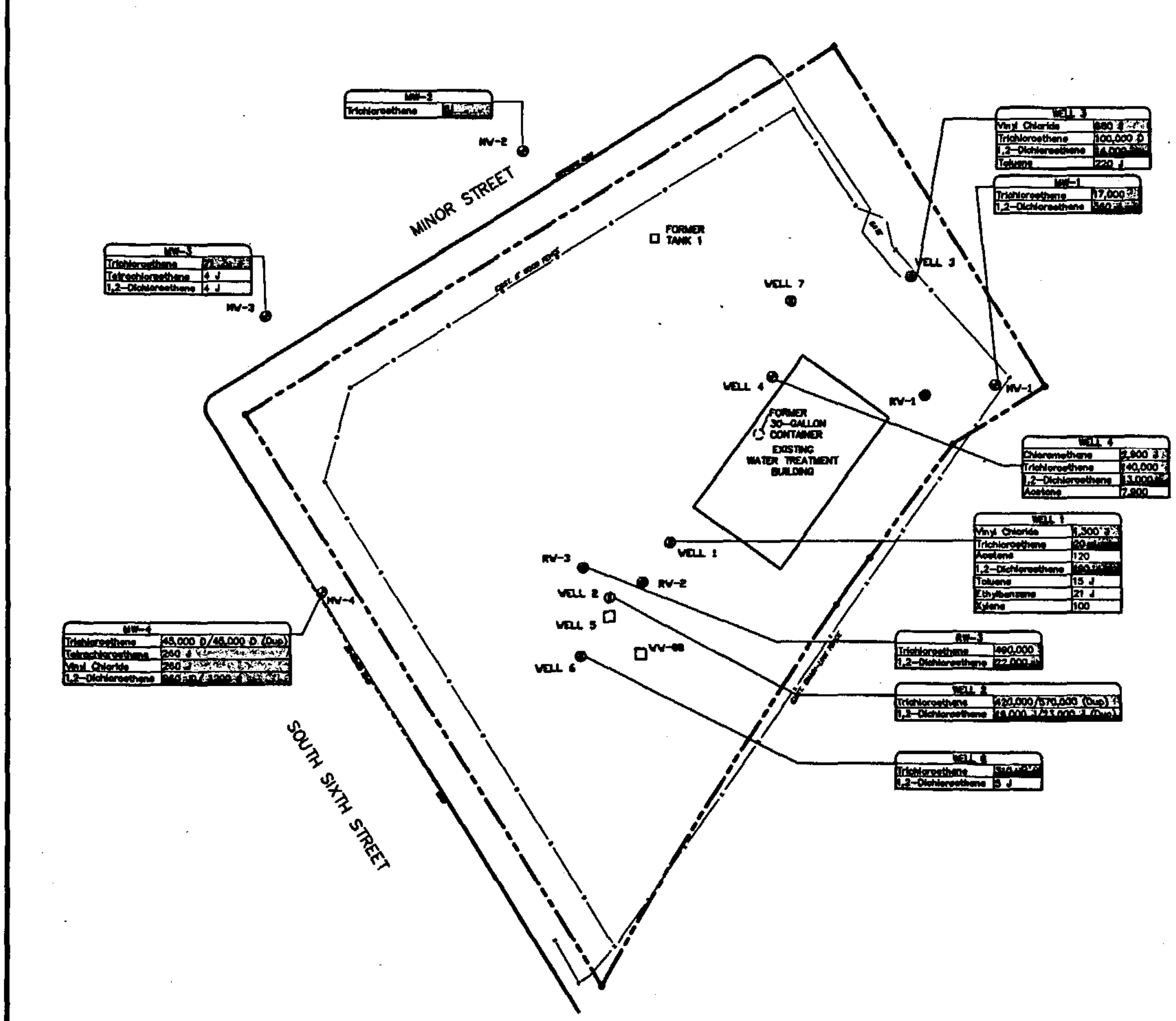
TECHNICAL IMPRACTICABILITY EVALUATION

SOIL BORING LOCATION MAP AND DETECTED VOLATILE ORGANIC COMPOUNDS IN SUBSURFACE SOIL SAMPLES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 5

2/16/96 SYR-54-GMS



L: ON=*, OFF=REF
P: [illegible]
2/16/98 SYR-54-GUS
[illegible]

LEGEND

MW-2	⊕	GROUND-WATER MONITORING WELL
WELL 7	◐	FORMER PRODUCTION/DISPOSAL WELL
RW-1	●	RECOVERY WELL
VV-08	□	CISTERN
	—·—·—	PROPERTY BOUNDARY
(Dup)		DUPLICATE SAMPLE
J		ESTIMATED VALUE, COMPOUND WAS DETECTED, BUT RESULTS ARE BELOW QUANTIFICATION LIMIT
D		COMPOUND WAS ANALYZED AT SECONDARY DILUTION

NOTES:

1. BASE MAP MODIFIED FROM BARRY ISETT AND ASSOCIATES, P.C. SURVEY, DATED 10/31/96.
2. ALL CONCENTRATIONS ARE REPORTED AS ug/L (ppb).
3. GROUND-WATER QUALITY DATA REPORTED FOR MW-4 WAS COLLECTED ON AUGUST 20, 1996. THE REMAINDER OF GROUND-WATER QUALITY DATA WAS COLLECTED JANUARY 8–14, 1997.
4. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLE LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
5. SHADED CONCENTRATIONS ARE ABOVE THE USEPA MCL AND PA ACT 2 GROUND-WATER STANDARDS.

SCALE:

40' 0 40'

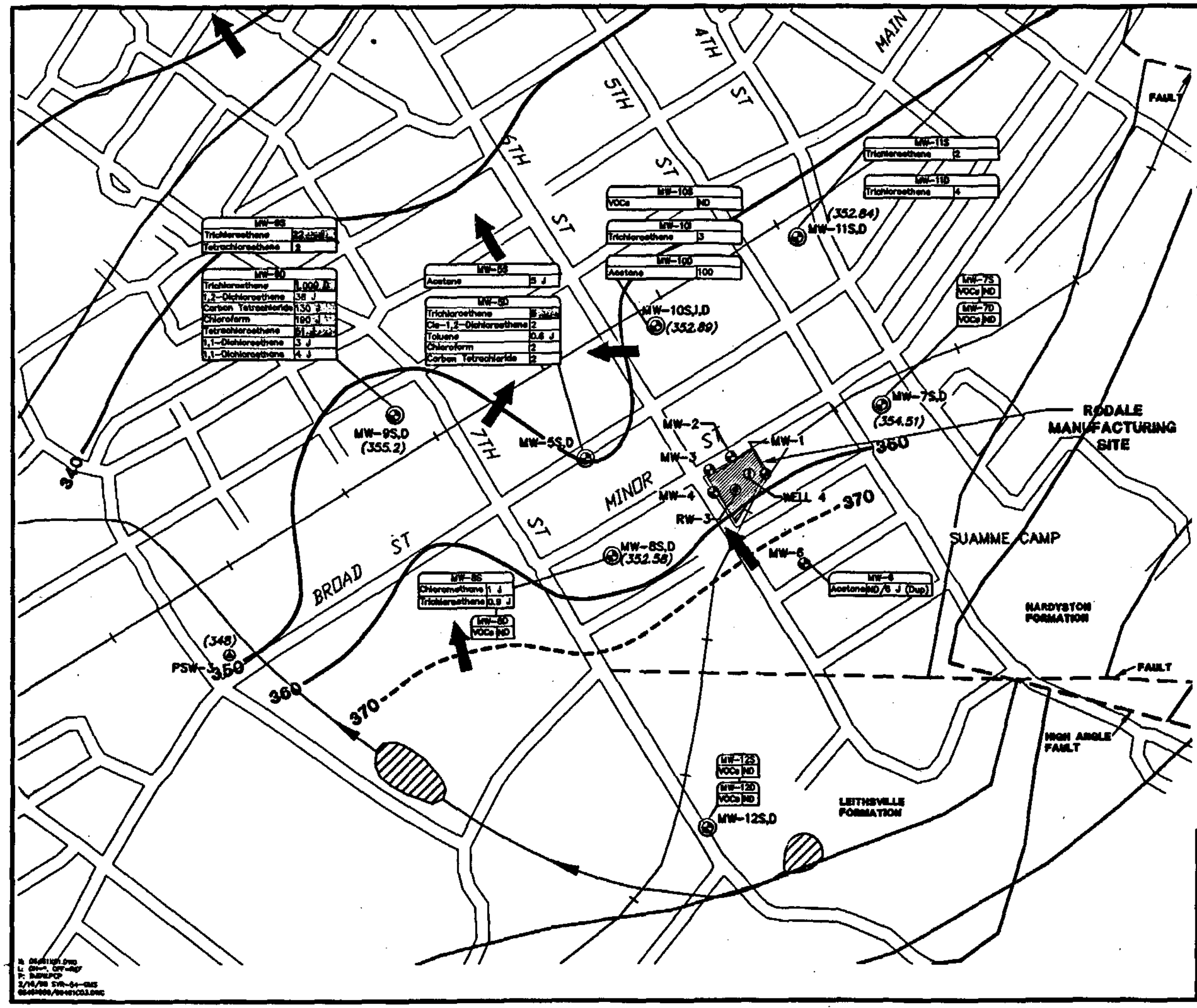
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS IN GROUND WATER AT ON-SITE AND ADJACENT WELLS

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
6



LEGEND

⊕	PUBLIC SUPPLY WELL
◎	MONITORING WELL CLUSTER
⊕	SHALLOW MONITORING WELL
⦶	FORMER DISPOSAL WELL
●	RECOVERY WELL
(352.89)	POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
360 ———	POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL). DASHED WHERE INFERRED
⬅	GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION [POTENTIOMETRIC SURFACE FOR DEEP WELLS (SEE ALSO FIGURES 29 AND 30)]
———	INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
———	INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)
(Dup)	DUPLICATE SAMPLE
ND	NOT DETECTED
J	ESTIMATED VALUE, COMPOUND WAS DETECTED, BUT RESULTS ARE BELOW QUANTIFICATION LIMIT
D	COMPOUND WAS ANALYZED AT SECONDARY DILUTION

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL CONCENTRATIONS ARE REPORTED AS ug/L (ppb).
4. SAMPLES OBTAINED JANUARY 9, 1997.
5. SHADED CONCENTRATIONS ARE ABOVE THE USEPA MCL AND PA ACT 2 GROUND-WATER STANDARDS.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
2. PLATE 2, C.R. WOOD et al. (1972), WATER RESOURCES OF LEHIGH COUNTY, PA.; COMMONWEALTH OF PA. DEPT. OF ENVIRONMENTAL RESOURCES, WATER RESOURCE REPORT 31.
3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
500' 0 500'

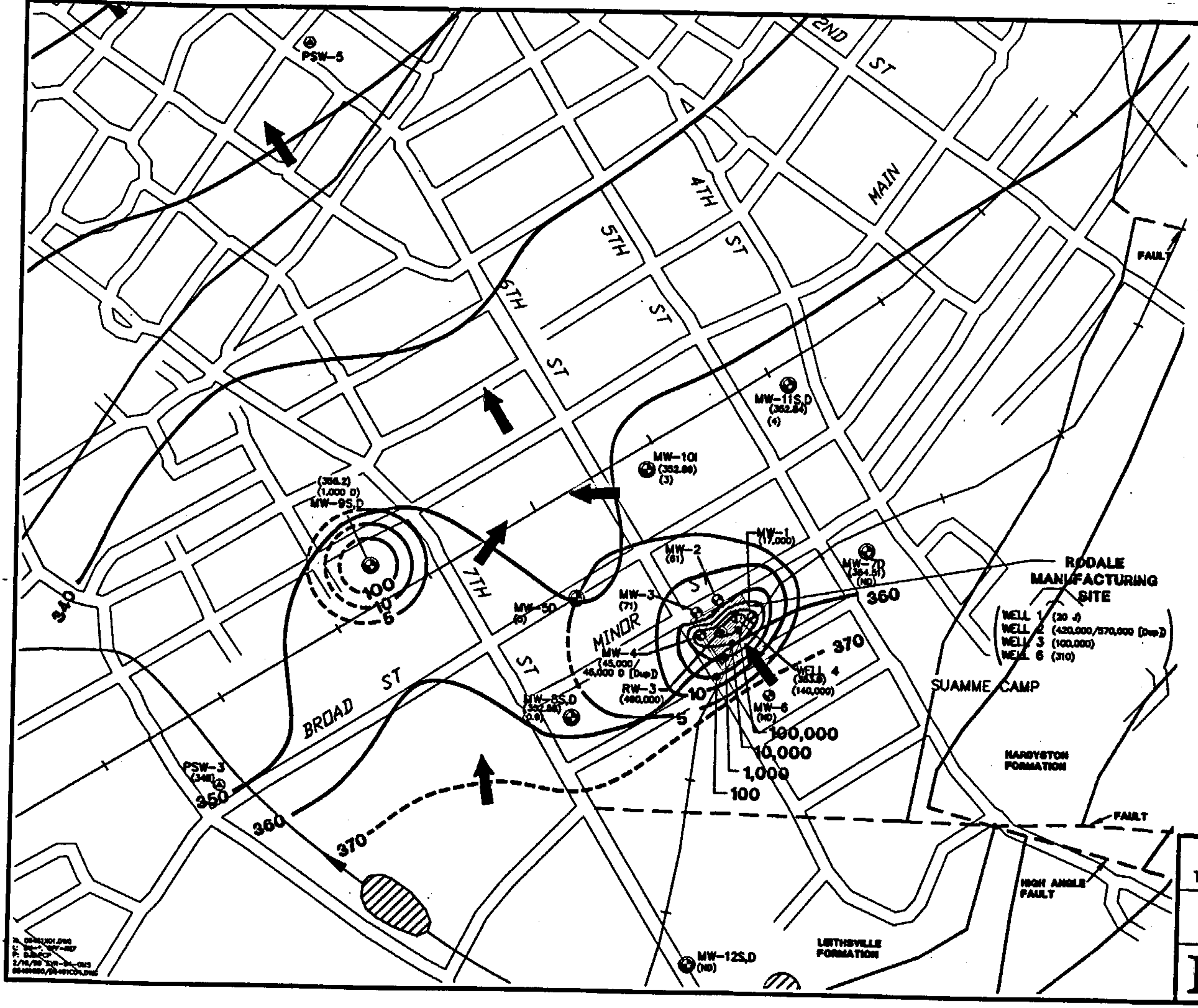
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

DISTRIBUTION OF VOLATILE ORGANIC COMPOUNDS IN GROUND WATER AT OFF-SITE MONITORING WELLS

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
7



LEGEND

◎ PUBLIC SUPPLY WELL

◎ MONITORING WELL CLUSTER

● SHALLOW MONITORING WELL

◎ FORMER DISPOSAL WELL

● RECOVERY WELL

(354.51) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL) FOR ~300FT DEPTH ZONE, AUGUST 19, 1996

360 ——— POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL), DASHED WHERE INFERRED

← GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION

——— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)

——— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

(140,000) TRICHLOROETHENE CONCENTRATION AS REPORTED IN ug/L (ppb)

100 ——— TRICHLOROETHENE CONCENTRATION CONTOUR AS REPORTED IN ug/L (ppb) (DASHED WHERE INFERRED)

[Dup] DUPLICATE SAMPLE

J ESTIMATED VALUE, COMPOUND WAS DETECTED, BUT RESULTS ARE BELOW QUANTIFICATION LIMIT

D COMPOUND WAS ANALYZED AT SECONDARY DILUTION

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL). (NGVD OF 1929).
4. GWTS NOT PUMPING.
5. MW-4 SAMPLE OBTAINED AUGUST 20, 1996 DURING AQUIFER PUMPING TEST.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
2. PLATE 2, C.R. WOOD et al. (1972), WATER RESOURCES OF LEHIGH COUNTY, PA.; COMMONWEALTH OF PA. DEPT. OF ENVIRONMENTAL RESOURCES, WATER RESOURCE REPORT 31.
3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
500' 0' 500'

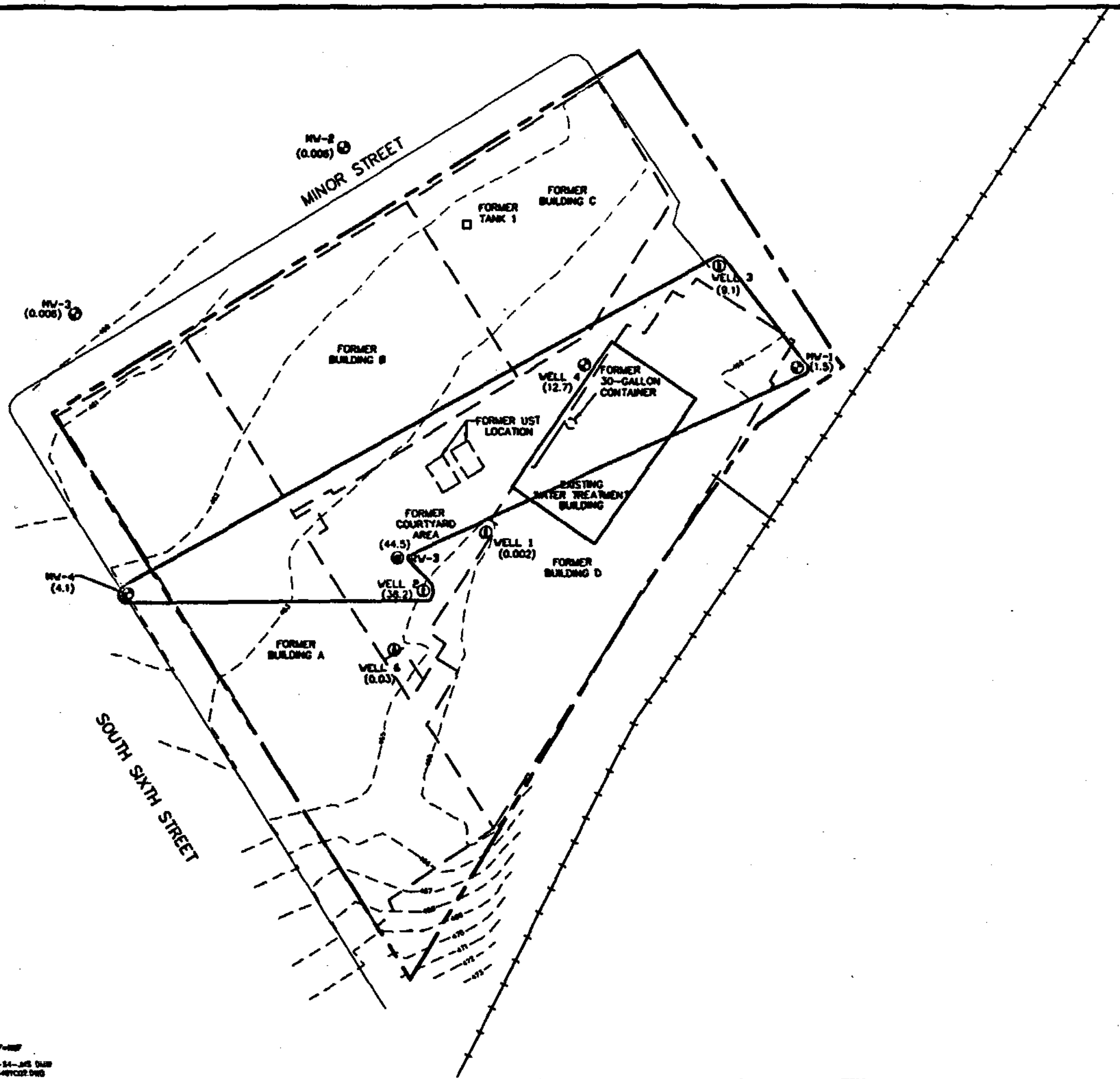
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

DISSOLVED TCE DISTRIBUTION AND GROUND-WATER FLOW DIRECTION

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 8



LEGEND

WELL 1 ⦶	FORMER DISPOSAL WELL
MW-2 ⊗	GROUND-WATER MONITORING WELL
RW-3 ●	RECOVERY WELL
▬ ▬ ▬	PROPERTY BOUNDARY
- - -469- - -	GROUND-SURFACE ELEVATION CONTOUR IN FEET ABOVE MEAN SEA LEVEL
— — —	FOOTPRINT OF FORMER BUILDING
(4.1)	PERCENT OF TCE SOLUBILITY
———	LIMITS OF PROBABLE DNAPL ZONE

NOTES:

1. BASE MAP DIGITIZED FROM SITE PLAN, PROVIDED IN RI/FS WORK PLAN (DEC. 1995).
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLE LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. PERCENT OF TCE SOLUBILITY VALUES CALCULATED USING JANUARY 9-14, 1997 GROUND-WATER ANALYTICAL DATA EXCEPT MW-4 FOR WHICH PERCENT SOLUBILITY WAS CALCULATED FROM AUGUST 20, 1996 GROUND-WATER DATA.
4. DEFINITION OF PROBABLE DNAPL ZONE DISCUSSED IN REPORT.

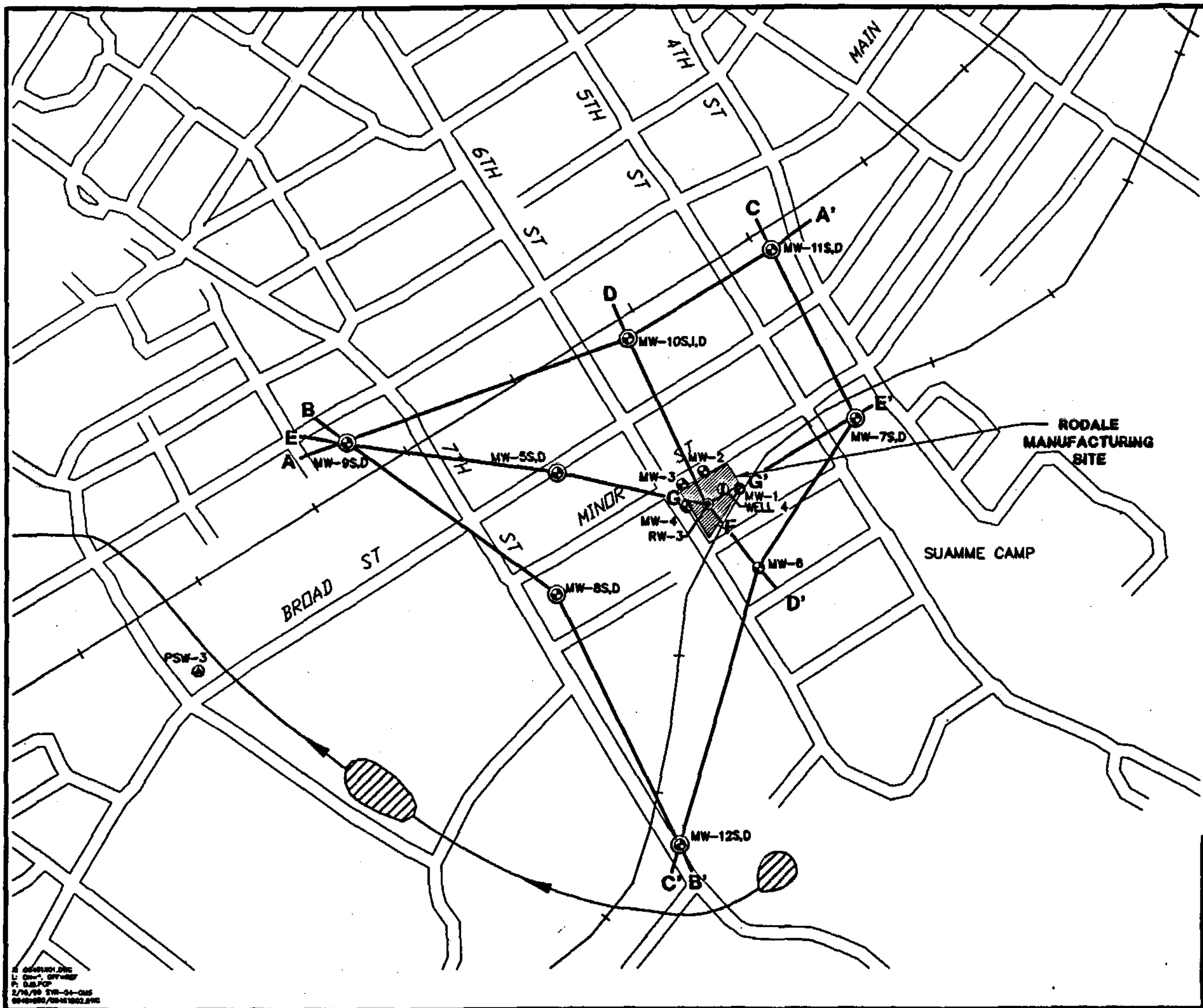
0 40' 80'
GRAPHIC SCALE

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

PROBABLE DNAPL ZONE

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
9



LEGEND

- ● PUBLIC SUPPLY WELL
- ◉ MONITORING WELL CLUSTER
- ● SHALLOW MONITORING WELL
- ● FORMER DISPOSAL WELL
- ● RECOVERY WELL
- A——A' CROSS SECTION LOCATION

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-READING, DATED 12/8/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.

SCALE:
0 500' 1000'

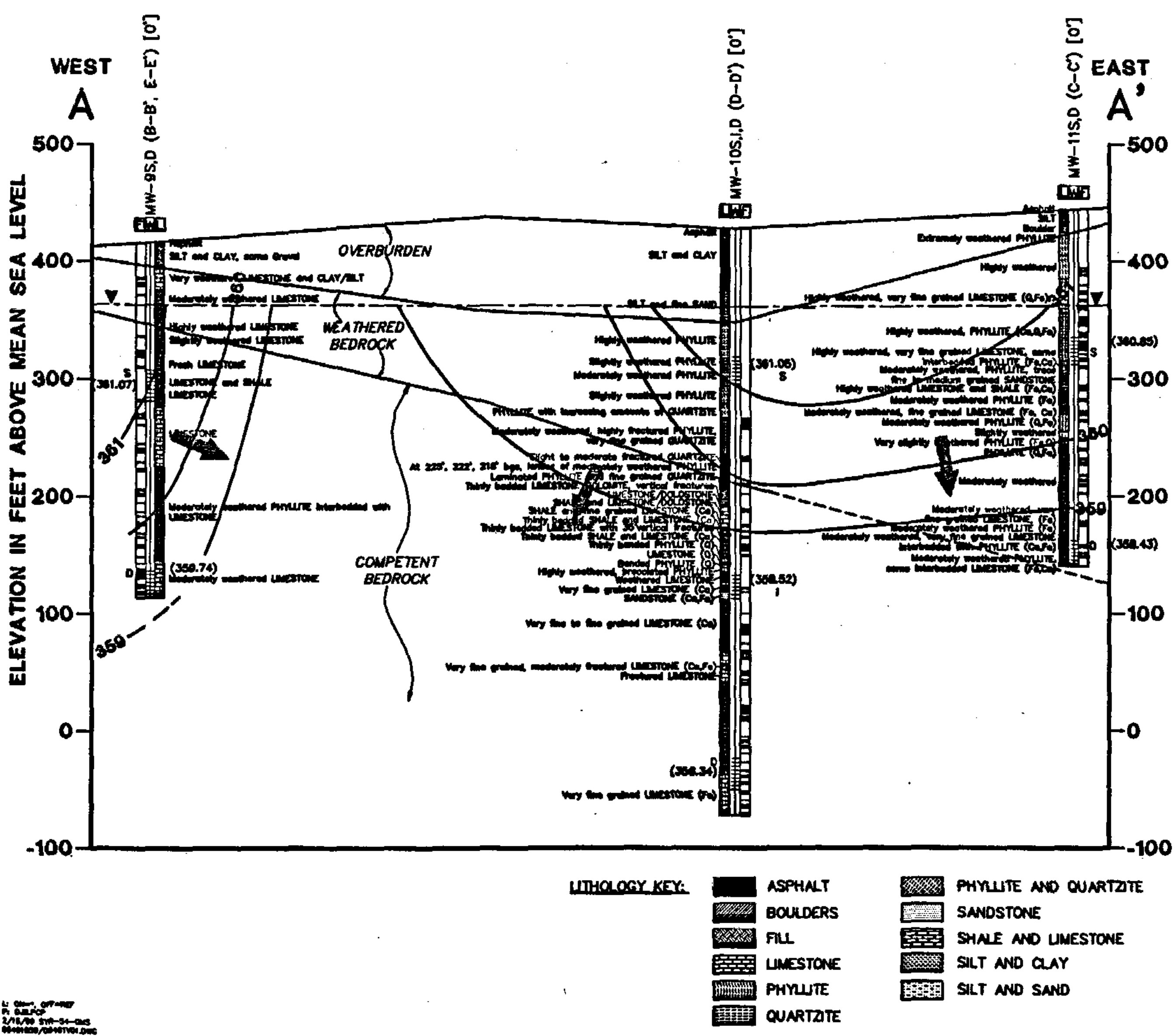
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

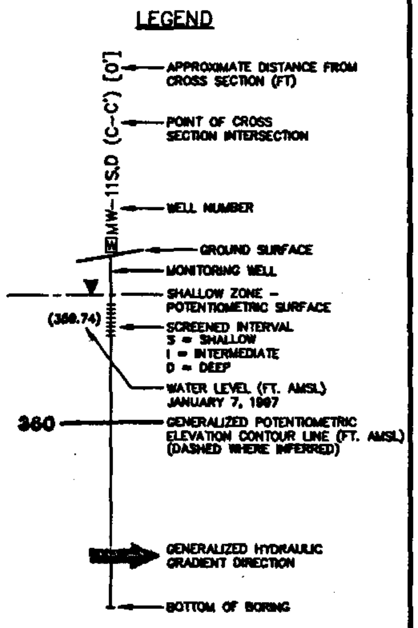
LOCATIONS OF CROSS SECTIONS

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
10

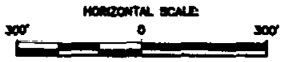


L: ON=*, OFF=REF
P: [illegible]
2/15/00 SYR-54-GMS
[illegible].DWG



NOTES:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. Ca = CALCITE MINERALIZATION
   Fe = IRON STAINING
   Q = QUARTZ FILLED RINGS OR JOINTS
3. F = FRACTURED AND WEATHERED ZONES IDENTIFIED BY BLACK ZONES (FROM SUBSURFACE LOGS)
   W = WELL SCREEN LOCATIONS
   L = LITHOLOGY DESCRIPTIONS (FROM SUBSURFACE LOGS)

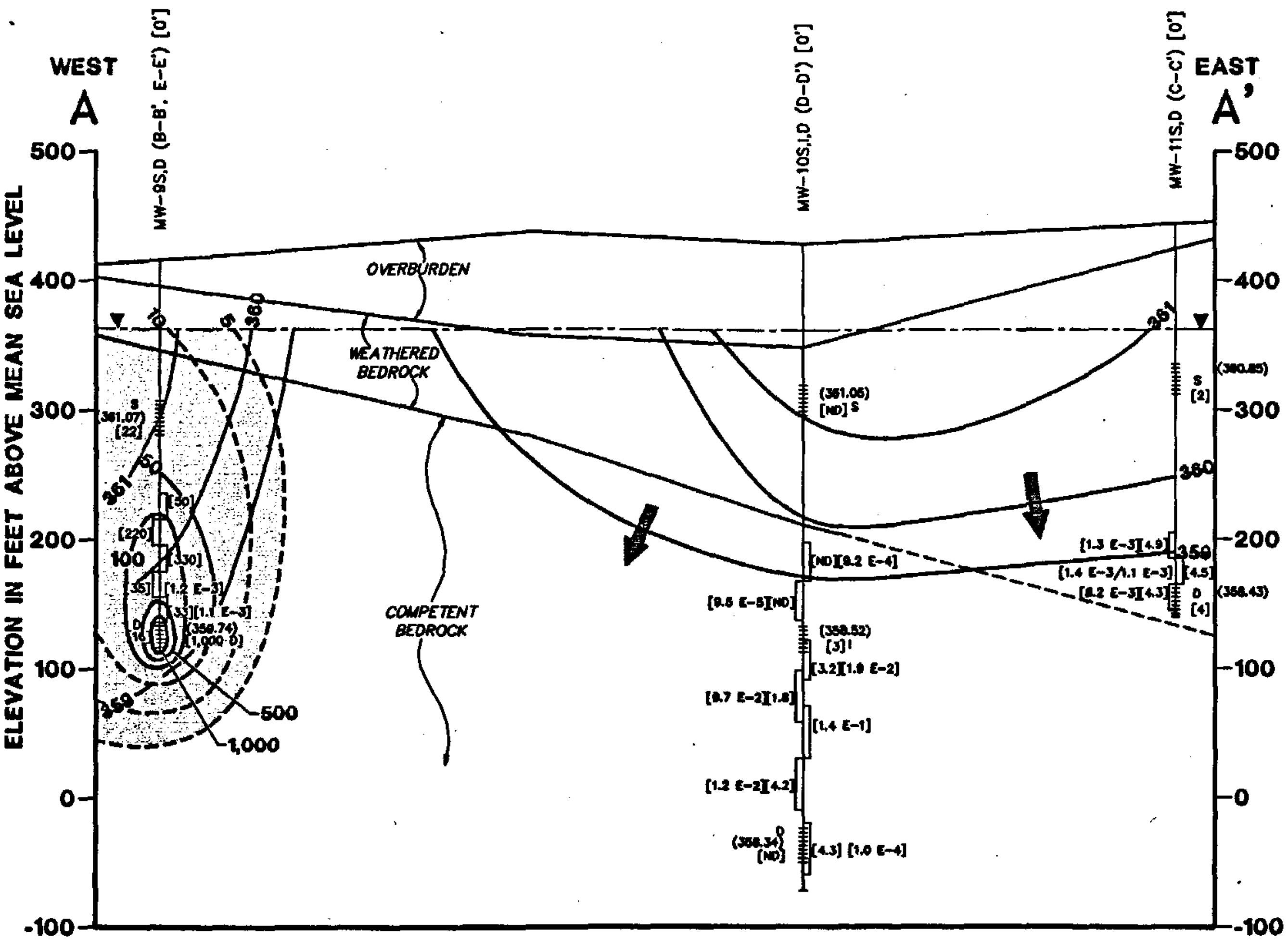


RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

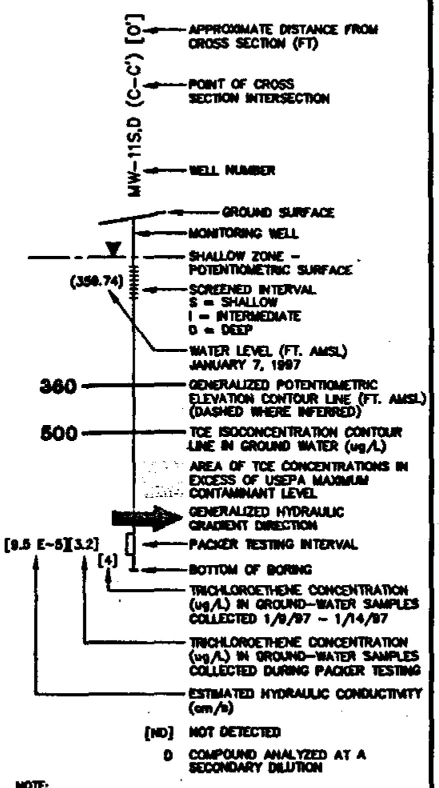
GEOLOGIC CROSS SECTION A-A'
AND FLOW NET DIAGRAM

BBL
BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
11



LEGEND



NOTE:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. TWO AQUIFER TESTS WERE PERFORMED FOR MW-11D, 185-165 FT AMSL.

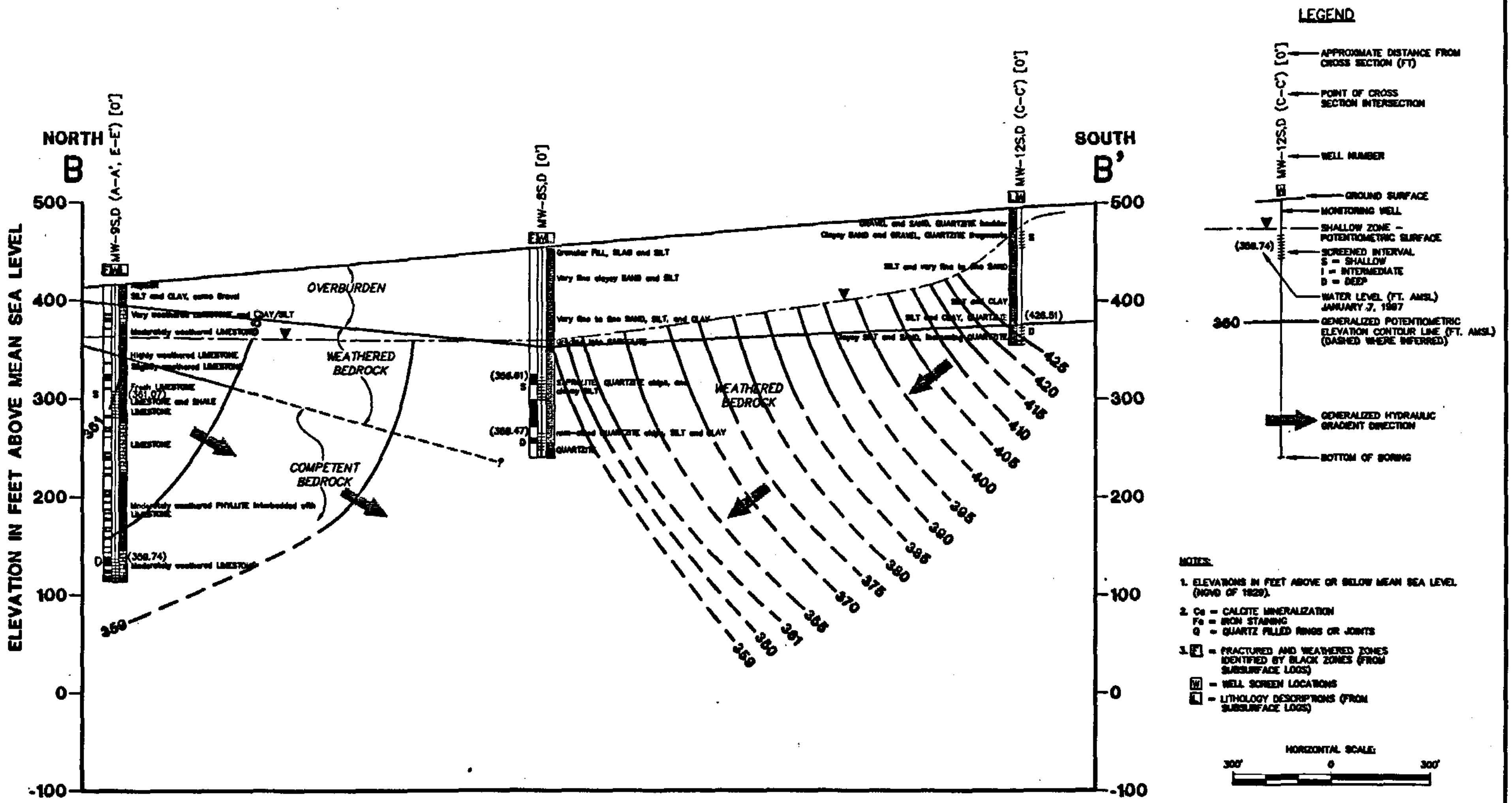
HORIZONTAL SCALE:
300' 0 300'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

HYDROGEOLOGIC CROSS SECTION A-A' AND TCE CONCENTRATIONS IN GROUND WATER

BBL
BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
11B



NOTES:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. Ca = CALCITE MINERALIZATION
   Fe = IRON STAINING
   Q = QUARTZ FILLED RINGS OR JOINTS
3. F = FRACTURED AND WEATHERED ZONES IDENTIFIED BY BLACK ZONES (FROM SUBSURFACE LOGS)
   W = WELL SCREEN LOCATIONS
   L = LITHOLOGY DESCRIPTIONS (FROM SUBSURFACE LOGS)

LITHOLOGY KEY:

- ■ ASPHALT
- ▨ FILL
- ▨ GRAVEL AND SAND
- ▤ LIMESTONE
- ▥ PHYLLITE
- ▦ QUARTZITE
- ▨ SILT AND CLAY
- ▨ SILT AND SAND

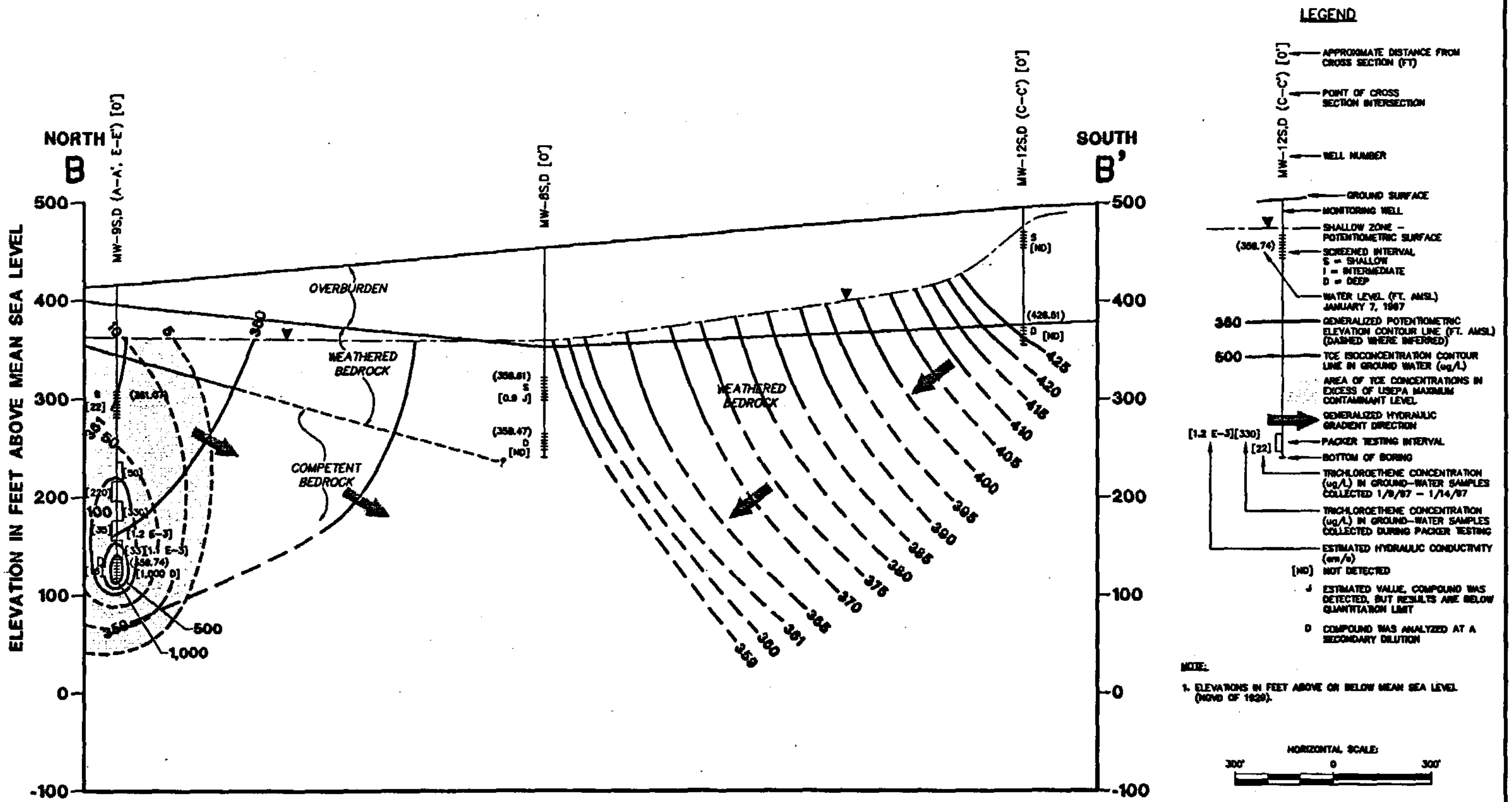
L: ON=*, OFF=REF
P: DJB/CP
2/15/99 SYR-54-GMS
[illegible]/[illegible].DWG

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

GEOLOGIC CROSS SECTION B-B' AND FLOW NET DIAGRAM

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
12



NOTE:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

HYDROGEOLOGIC CROSS SECTION B-B' AND TCE CONCENTRATIONS IN GROUND WATER

BBL
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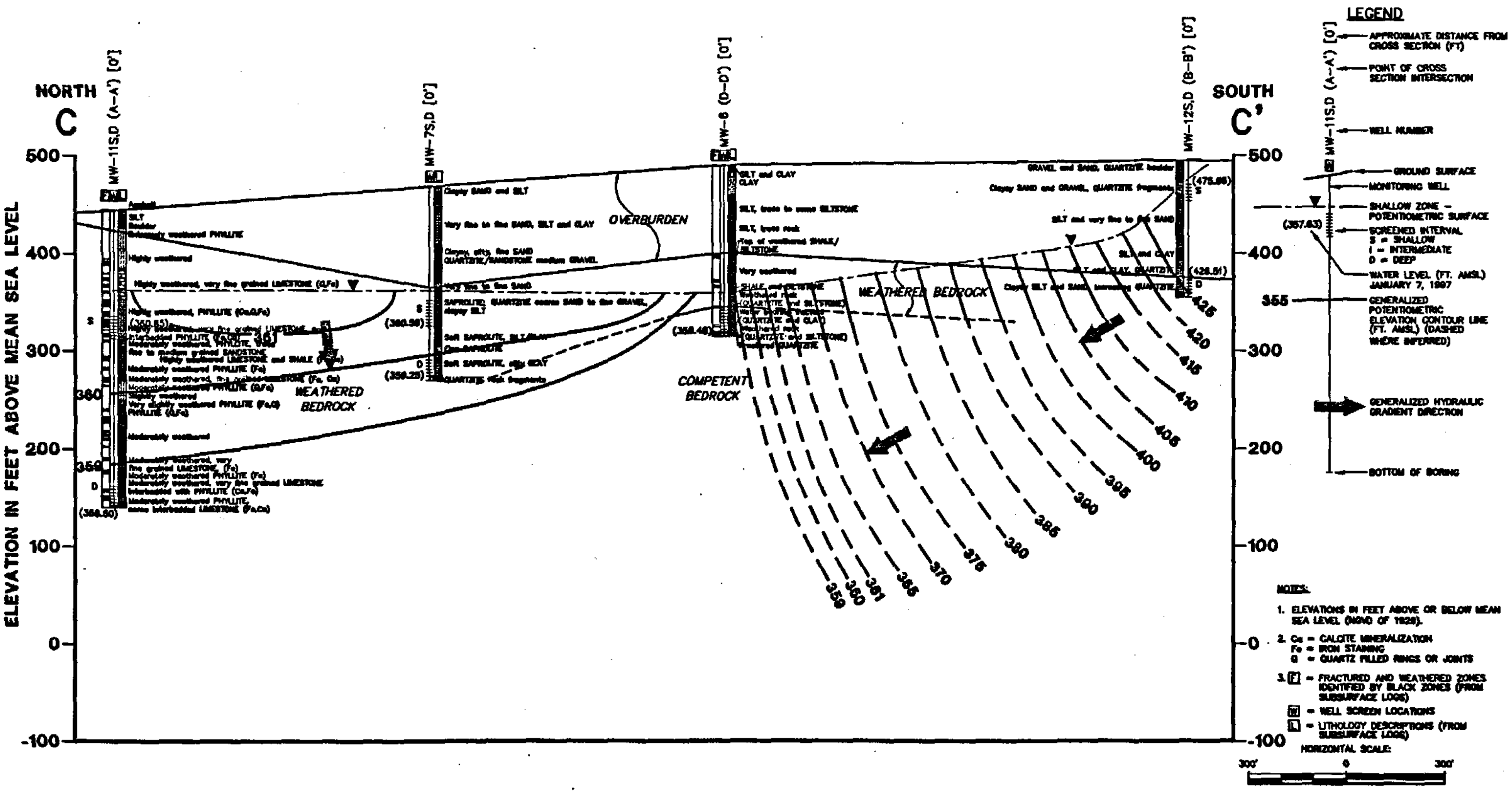
engineers & scientists

FIGURE
12B



NOTES:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. Ca = CALCITE MINERALIZATION
   Fe = IRON STAINING
   Q = QUARTZ FILLED RINGS OR JOINTS
3. F = FRACTURED AND WEATHERED ZONES IDENTIFIED BY BLACK ZONES (FROM SUBSURFACE LOGS)
   W = WELL SCREEN LOCATIONS
   L = LITHOLOGY DESCRIPTIONS (FROM SUBSURFACE LOGS)

LITHOLOGY KEY:

■	ASPHALT	▨	PHYLLITE AND QUARTZITE
▨	BOULDERS	▤	QUARTZITE AND SILTSTONE
▨	GRAVEL AND SAND	▨	SANDSTONE
▤	LIMESTONE	▤	SHALE AND LIMESTONE
▥	PHYLLITE	▨	SILT AND CLAY
▦	QUARTZITE	▨	SILT AND SAND

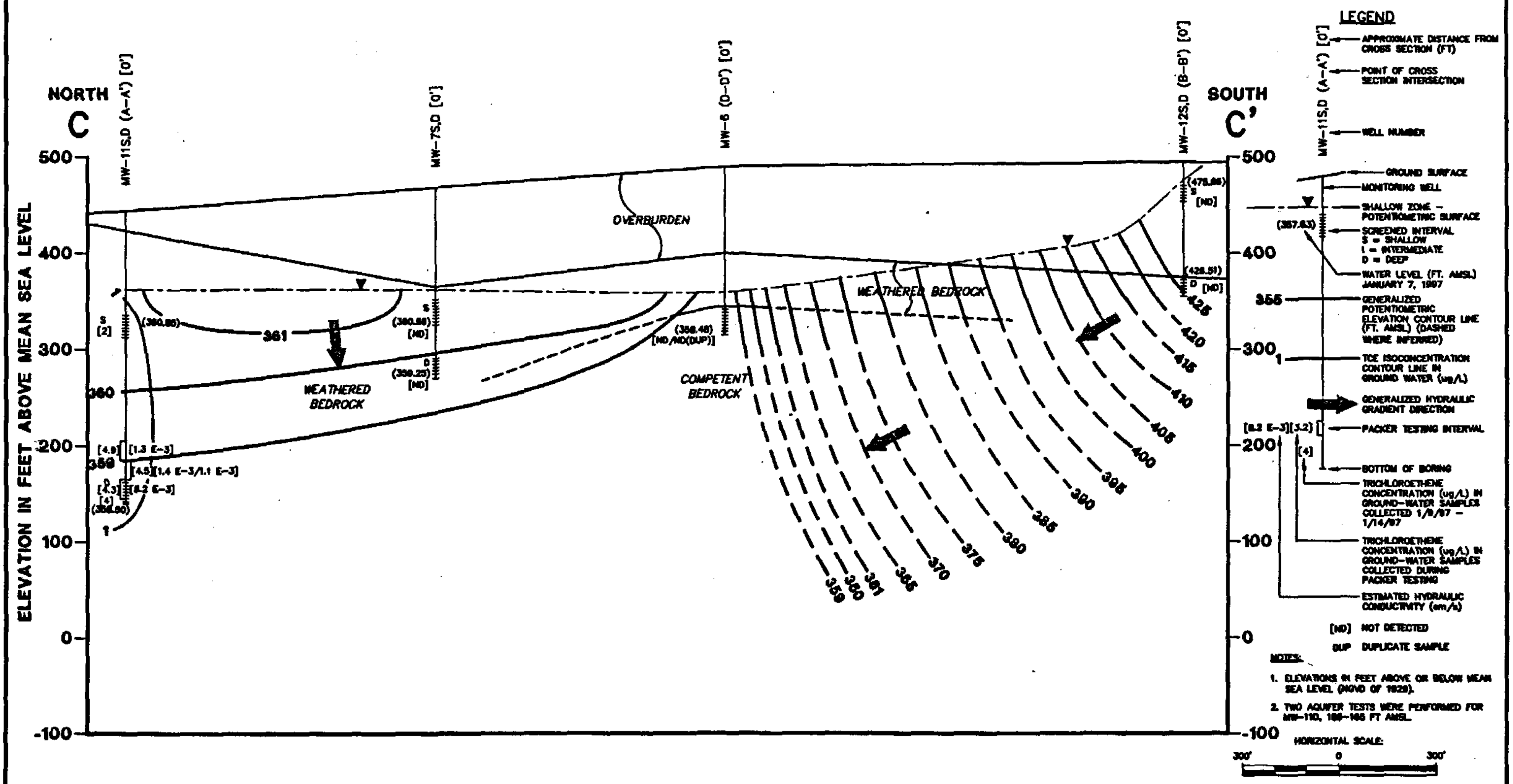
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

GEOLOGIC CROSS SECTION C-C' AND FLOW NET DIAGRAM

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
13



NOTES:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. TWO AQUIFER TESTS WERE PERFORMED FOR MW-11D, 186-165 FT AMSL.

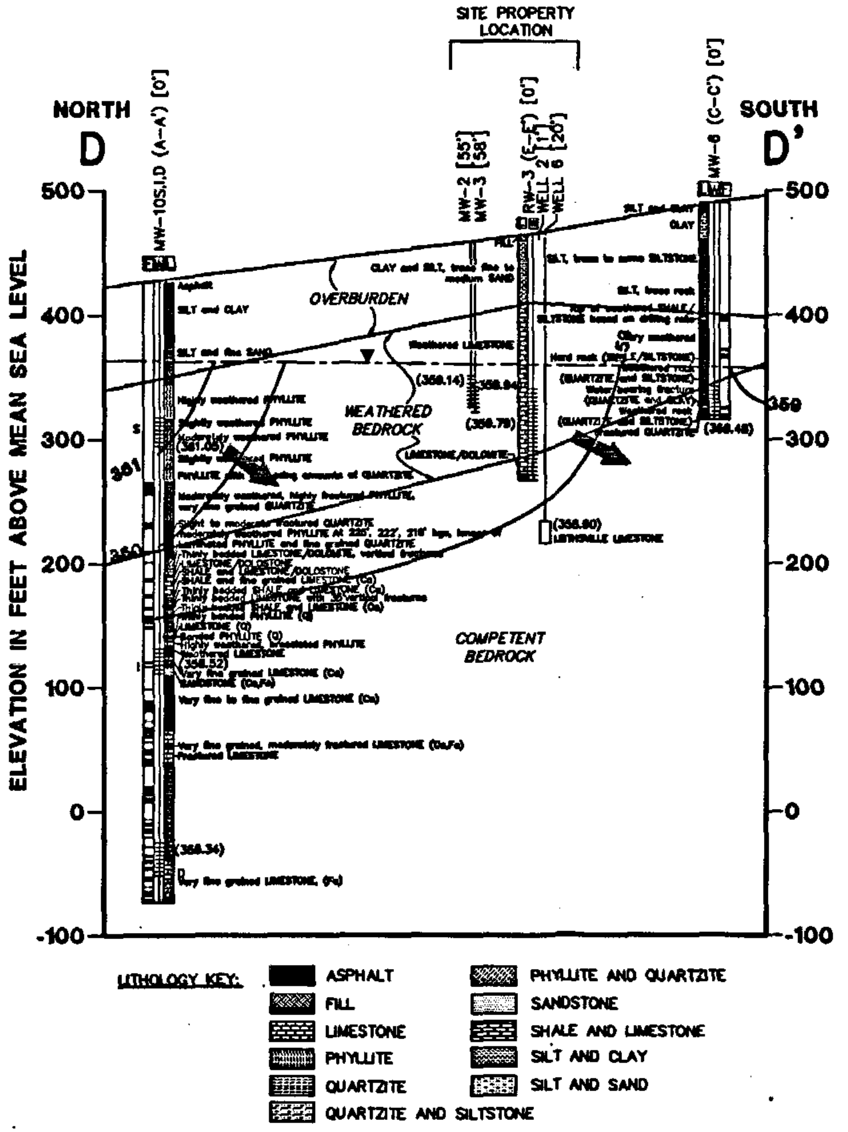
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

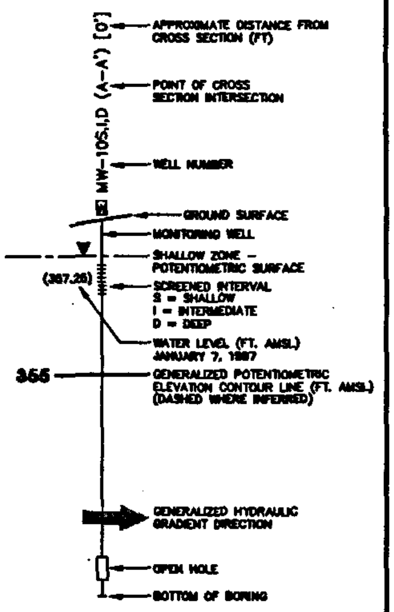
HYDROGEOLOGIC CROSS SECTION C-C' AND TCE CONCENTRATIONS IN GROUND WATER

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 13B



LEGEND



NOTES:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. Ca = CALCITE MINERALIZATION
   Fe = IRON STAINING
   Q = QUARTZ FILLED RINGS OR JOINTS
3. F = FRACTURED AND WEATHERED ZONES IDENTIFIED BY BLACK ZONES (FROM SUBSURFACE LOGS)
   W = WELL SCREEN LOCATIONS
   L = LITHOLOGY DESCRIPTIONS (FROM SUBSURFACE LOGS)
4. FRACTURED AND WEATHERED ZONES FOR RW-3 NOT AVAILABLE.

HORIZONTAL SCALE:
300' 0 300'

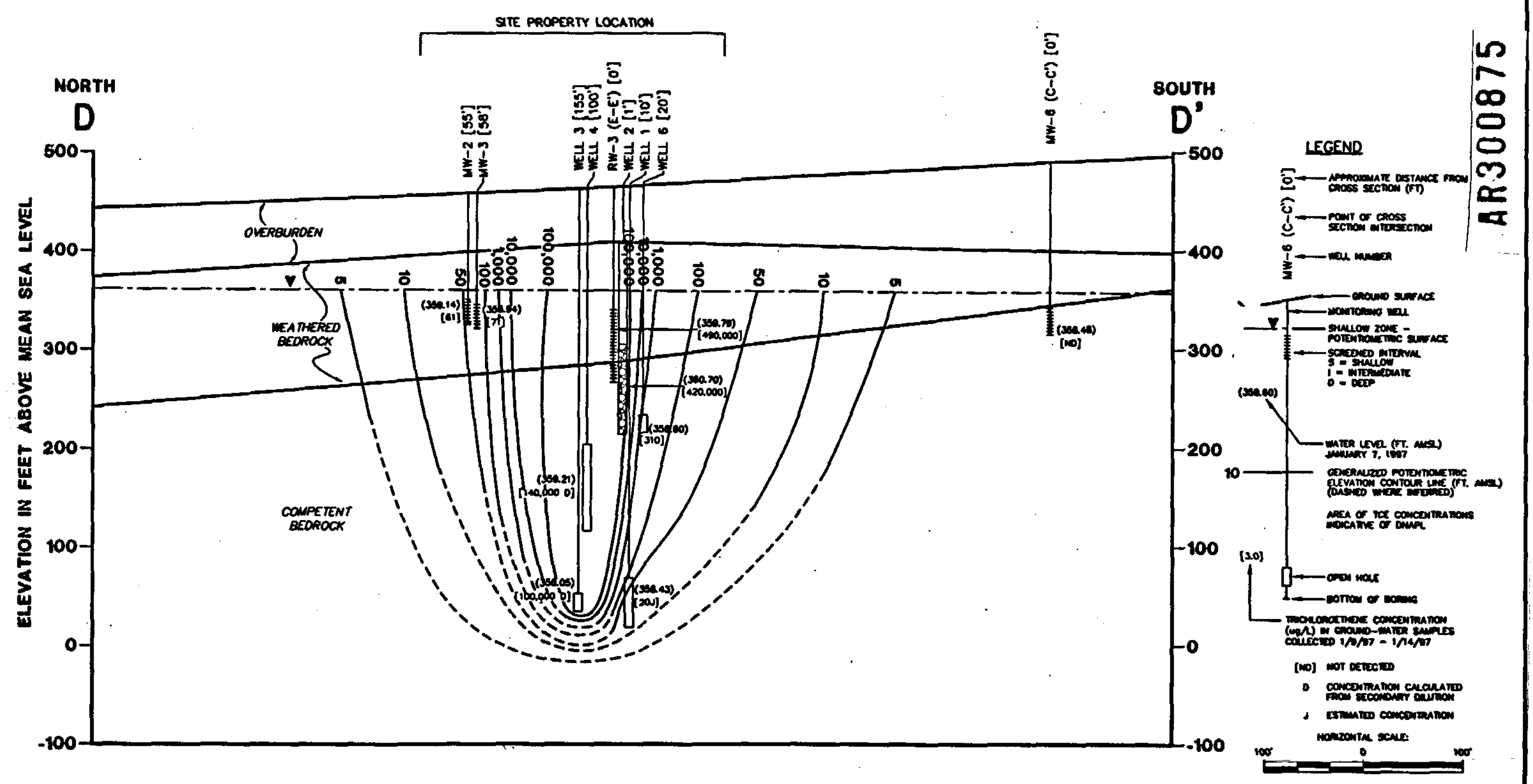
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

GEOLOGIC CROSS SECTION D-D' AND FLOW NET DIAGRAM

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
14

L: [illegible]
P: [illegible]
2/16/00 SYR-54-[illegible]
[illegible]V07.DWG



RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

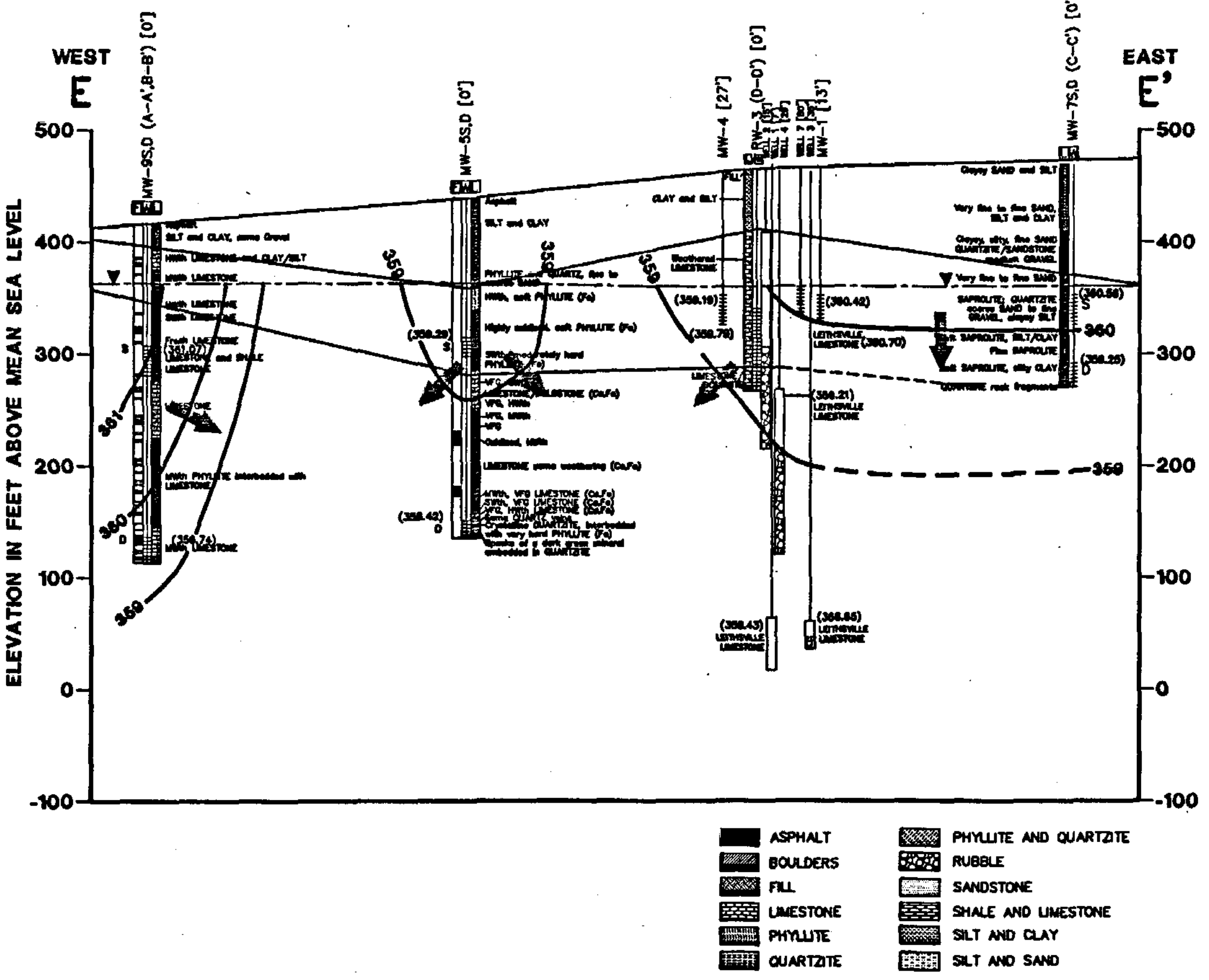
TECHNICAL IMPRACTICABILITY EVALUATION

HYDROGEOLOGIC CROSS SECTION D-D' AND TCE CONCENTRATIONS IN GROUND WATER

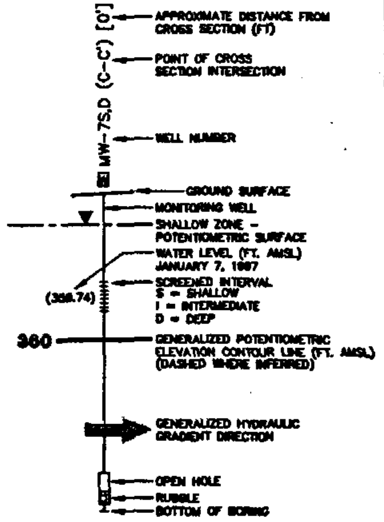
BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
14B

08461070/08461V12.DWG



LEGEND



NOTES:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. Ca = CALCITE MINERALIZATION
   Fe = IRON STAINING
   Q = QUARTZ FILLED RINGS OR JOINTS
   HWth = HIGHLY WEATHERED
   MWth = MODERATELY WEATHERED
   SWth = SLIGHTLY WEATHERED
   VFG = VERY FINE GRAINED
3. F = FRACTURED AND WEATHERED ZONES IDENTIFIED BY BLACK ZONES (FROM SUBSURFACE LOGS)
   W = WELL SCREEN LOCATIONS
   L = LITHOLOGY DESCRIPTIONS (FROM SUBSURFACE LOGS)

HORIZONTAL SCALE:
300' 0 300'

L: ON=*, OFF=REF
P: DJB/CP
2/15/99 SYR-54-CVS
[illegible]

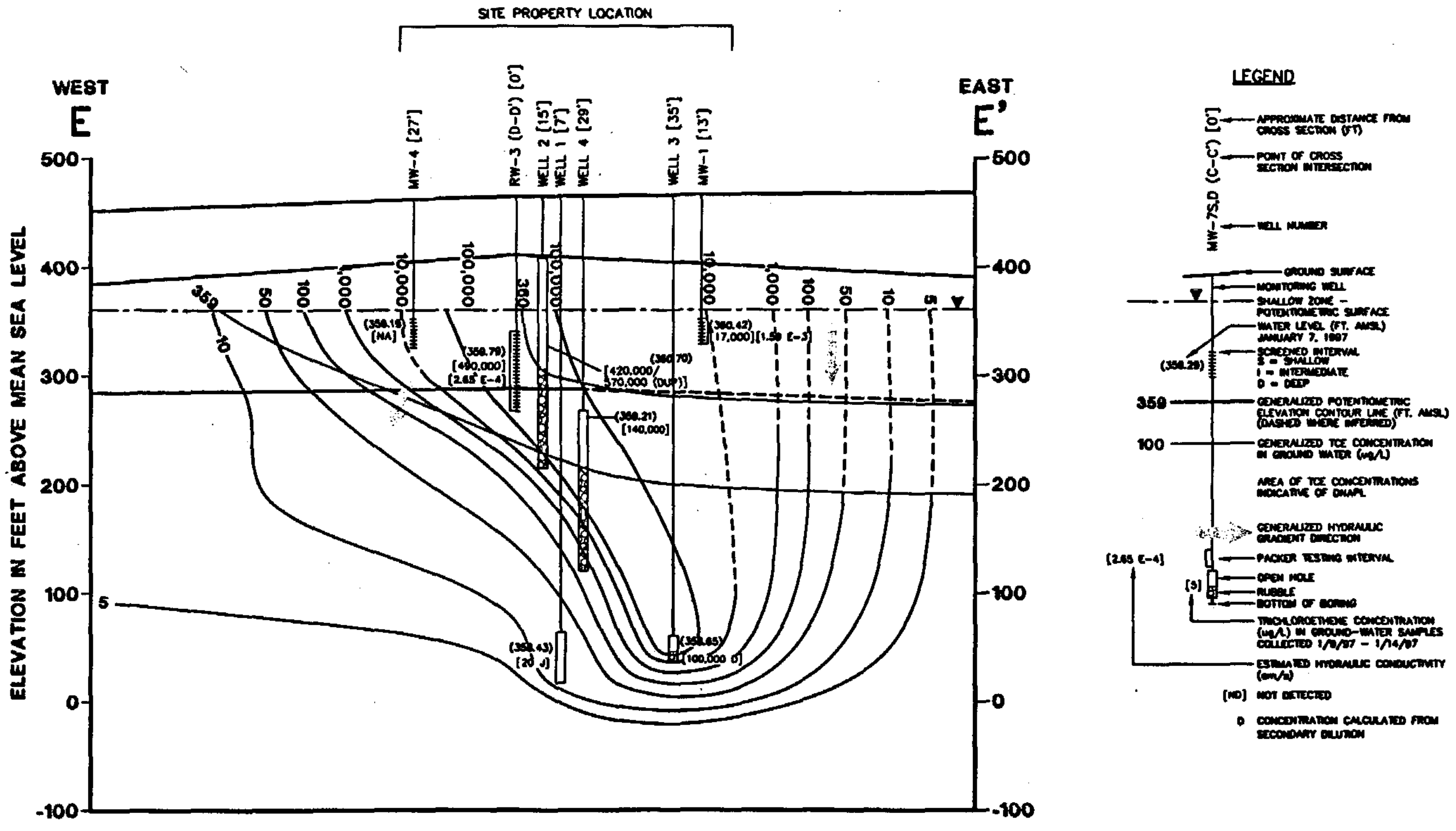
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

GEOLOGIC CROSS SECTION E-E' AND FLOW NET DIAGRAM

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 15



NOTE:

1. ELEVATIONS IN FEET ABOVE OR BELOW MEAN SEA LEVEL (NGVD OF 1929).
2. RW-3 PUMPING TEST RESULTS USING JACOB STRAIGHT-LINE METHOD (cm/s), FROM APPENDIX L.

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

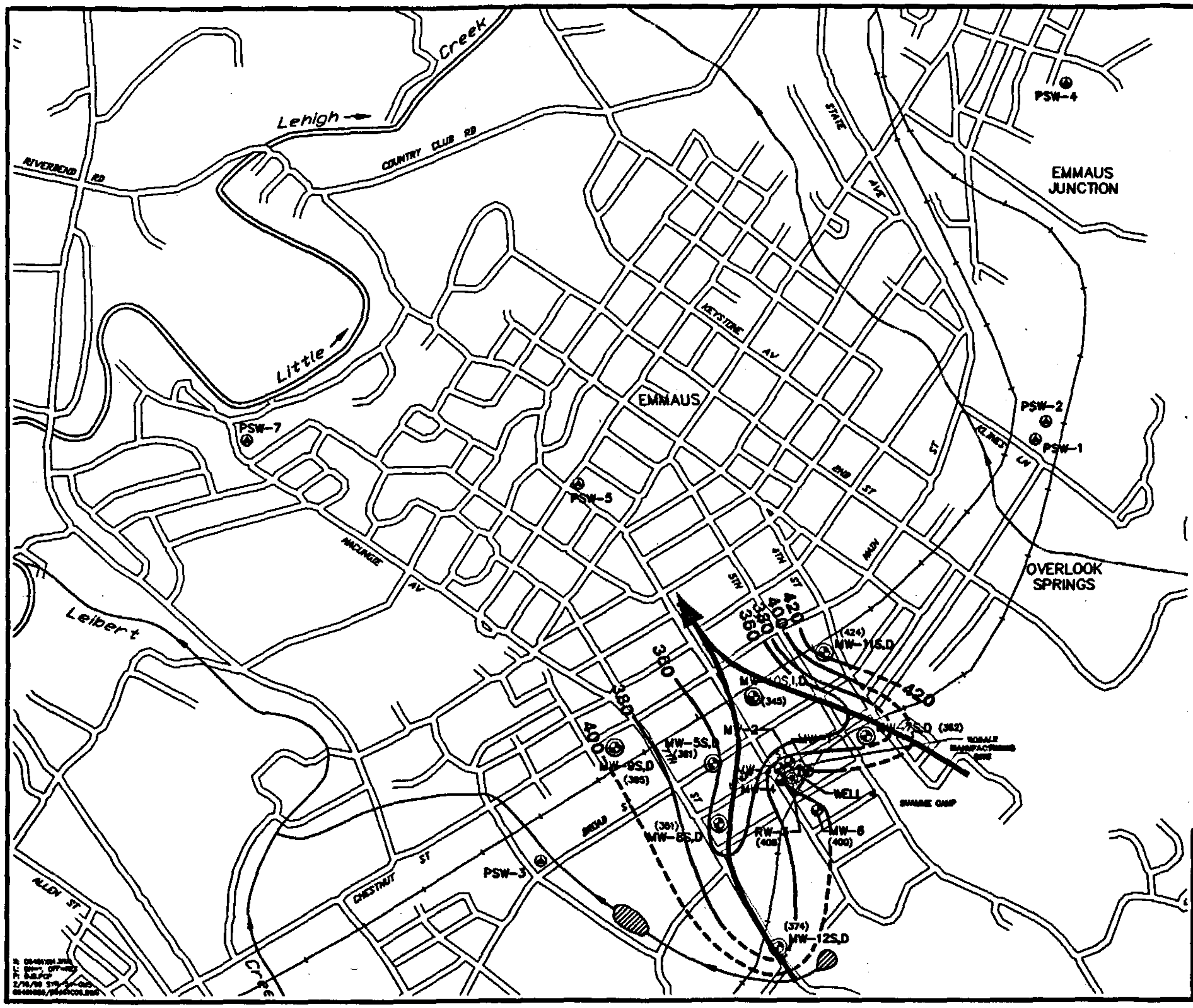
TECHNICAL IMPRACTICABILITY EVALUATION

HYDROGEOLOGIC CROSS SECTION E-E' AND TCE CONCENTRATIONS IN GROUND WATER

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 15B

L: ON=*, OFF=REF
P: [illegible]
8/17/98 SYR-54-DMS [illegible]
[illegible]



LEGEND

- ● PUBLIC SUPPLY WELL
- ◎ MONITORING WELL CLUSTER
- ● SHALLOW MONITORING WELL
- ● FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (345) TOP OF WEATHERED BEDROCK ELEVATION (FT. AMSL)
- 360 —— TOP OF WEATHERED BEDROCK ELEVATION CONTOUR LINE (FT. AMSL) DASHED WHERE INFERRED
- ← APPARENT PALEOCHANNEL

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REB.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLE LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL). (NGVD OF 1929).

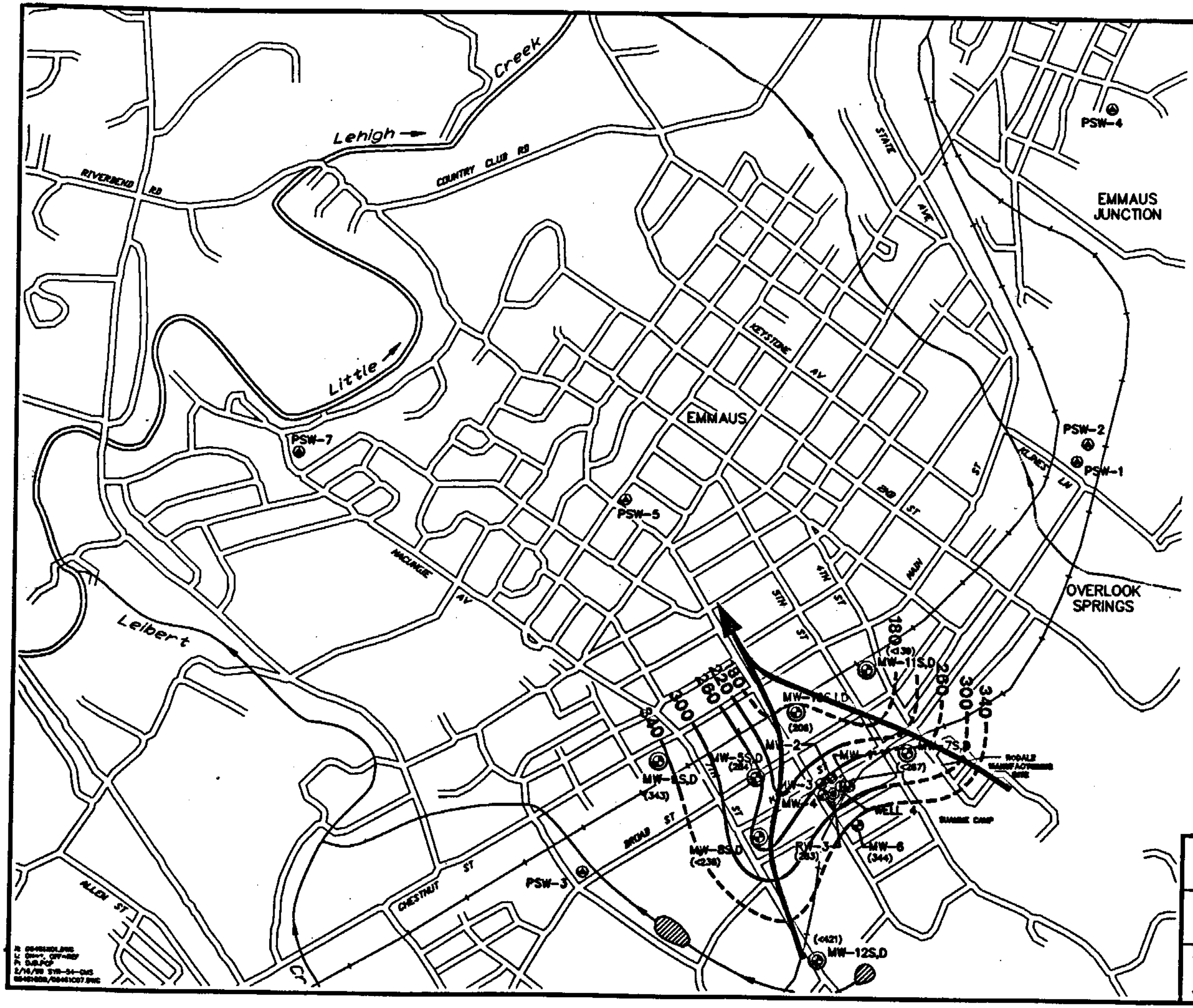
SCALE:
1000' 0 1000'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

WEATHERED BEDROCK
SURFACE

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
16



LEGEND

- ◉ PUBLIC SUPPLY WELL
- ◉ MONITORING WELL CLUSTER
- ◉ SHALLOW MONITORING WELL
- ◉ FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (344) TOP OF BEDROCK ELEVATION (FT. AMSL)
- 360 —— TOP OF BEDROCK ELEVATION CONTOUR LINE (FT. AMSL), DASHED WHERE INFERRED
- ◀━━ APPARENT PALEOCHANNEL

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLE LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL). (NGVD OF 1929).

SCALE:
1000' 0 1000'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

COMPETENT BEDROCK
SURFACE

BBL
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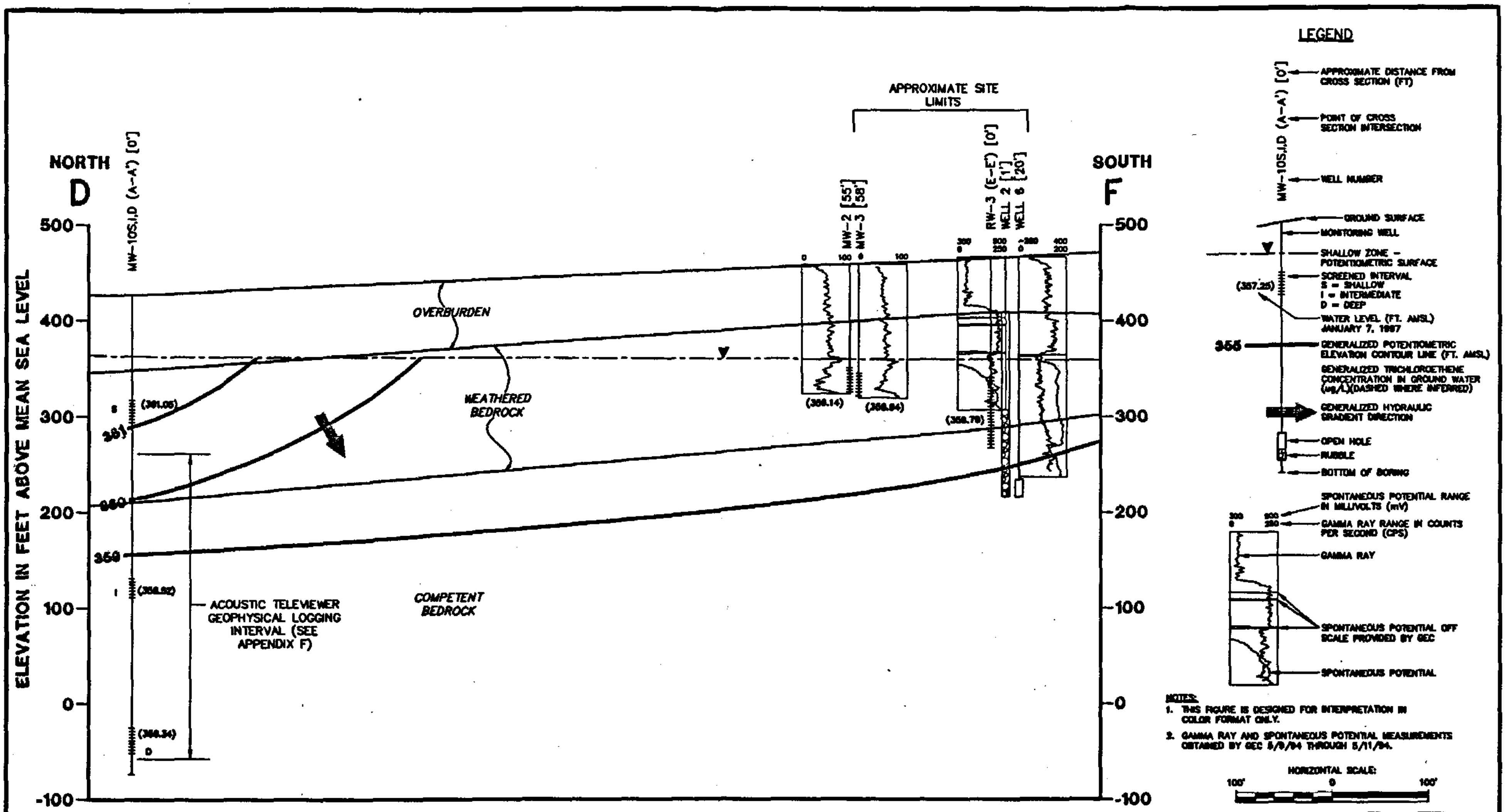
engineers & scientists

FIGURE
17



NOTES:

1. THIS FIGURE IS DESIGNED FOR INTERPRETATION IN COLOR FORMAT ONLY.
2. GAMMA RAY AND SPONTANEOUS POTENTIAL MEASUREMENTS OBTAINED BY GEC 5/9/94 THROUGH 5/11/94.

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

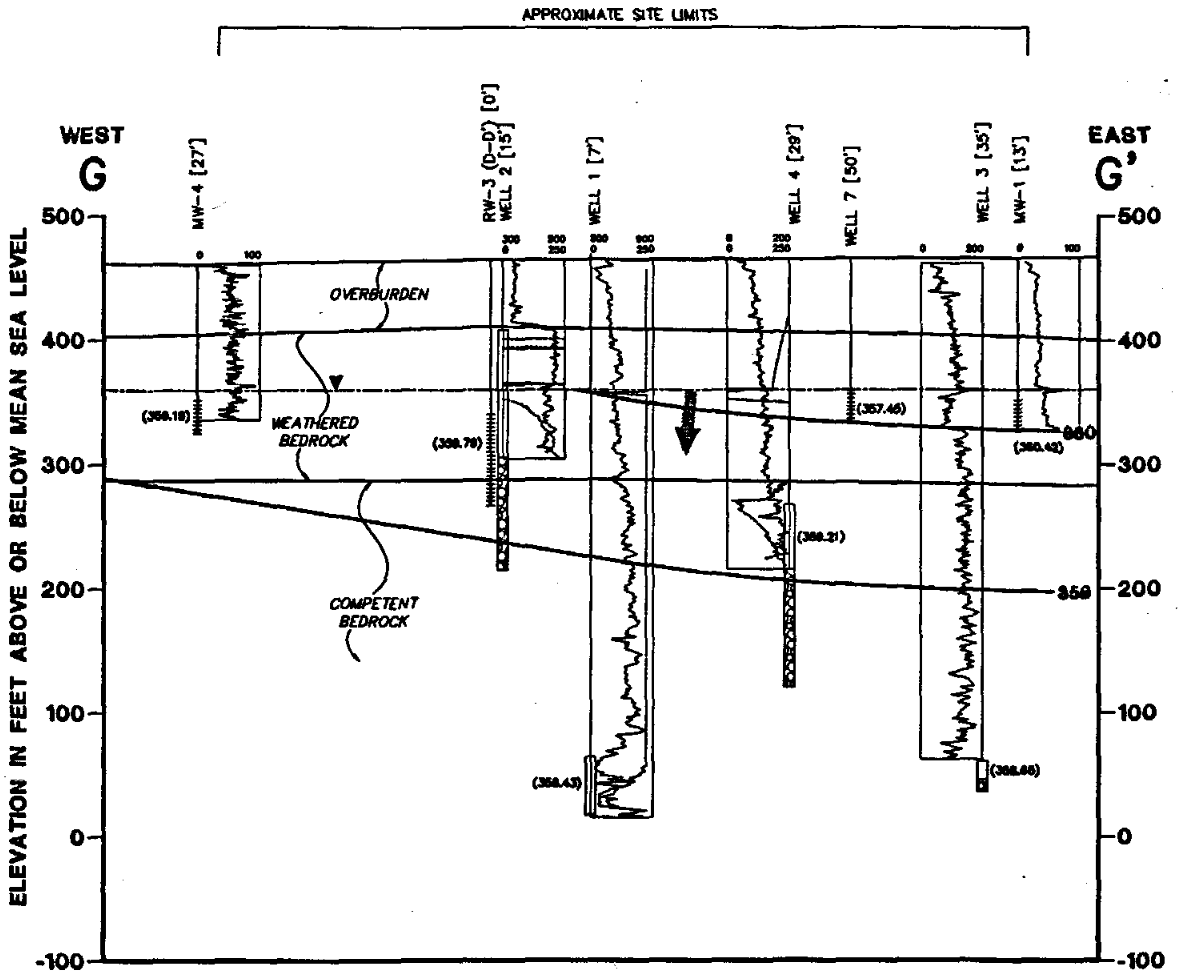
TECHNICAL IMPRACTICABILITY EVALUATION

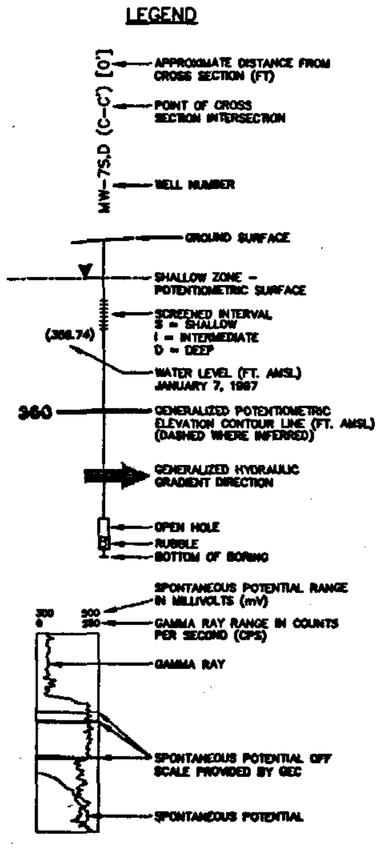
GEOPHYSICAL CROSS SECTION D-F AND FLOW NET DIAGRAM

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
18

L: ON=*, OFF=REF
P: D-B.PCP
2/16/99 SYR-54-GMS
[illegible]/[illegible].DWG





NOTES:

1. THIS FIGURE IS DESIGNED FOR INTERPRETATION IN COLOR FORMAT ONLY.
2. GAMMA RAY AND SPONTANEOUS POTENTIAL MEASUREMENTS OBTAINED BY GEC 5/9/94 THROUGH 5/24/94.

HORIZONTAL SCALE:

40' 0 40'

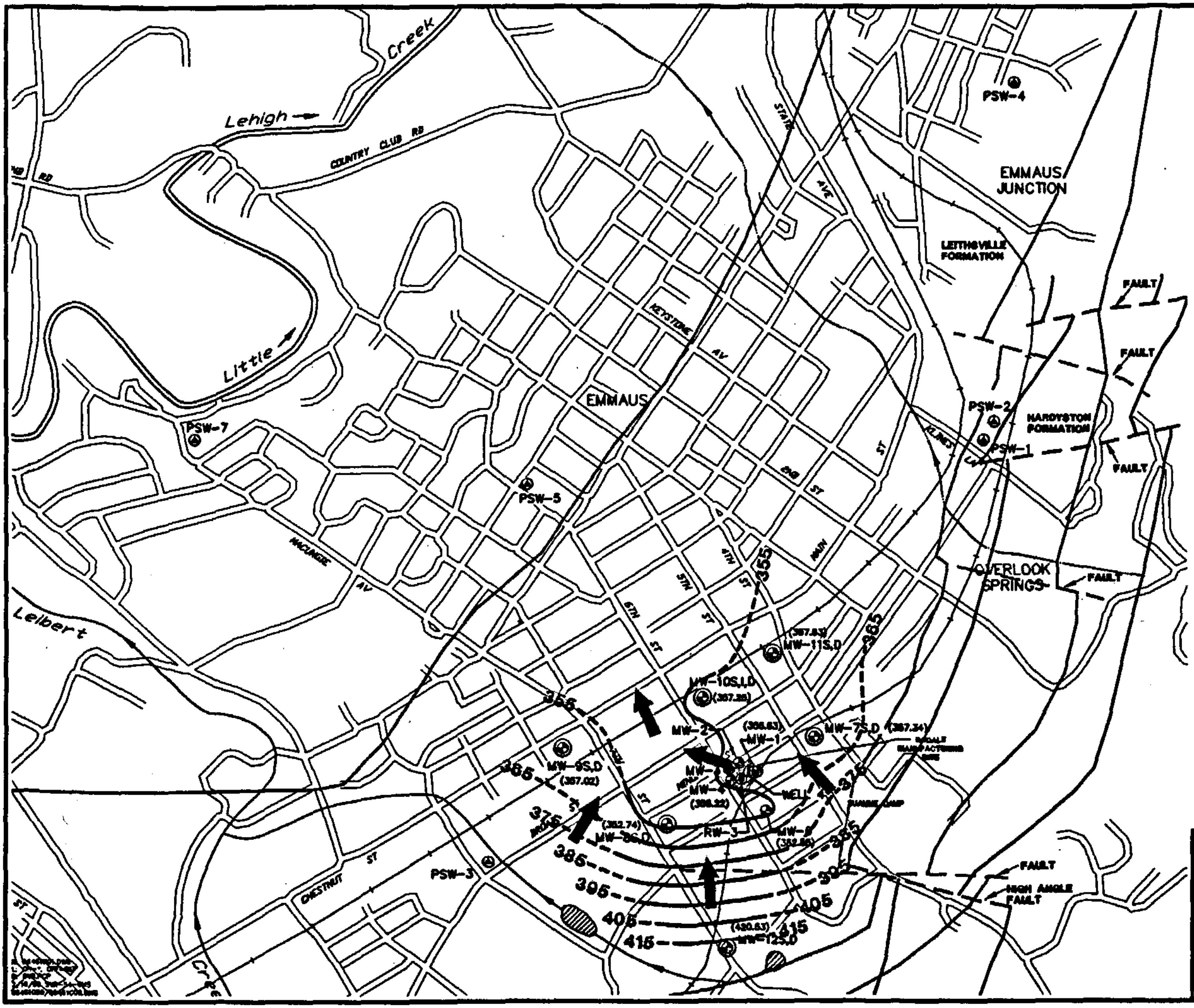
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

GEOPHYSICAL CROSS SECTION G-G' AND FLOW NET DIAGRAM

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 19



LEGEND

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL). (NGVD OF 1929).

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
2. PLATE 2, C.R. WOOD et al. (1972), WATER RESOURCES OF LEHIGH COUNTY, PA.; COMMONWEALTH OF PA. DEPT. OF ENVIRONMENTAL RESOURCES, WATER RESOURCE REPORT 31.
3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
1000' 0 1000'

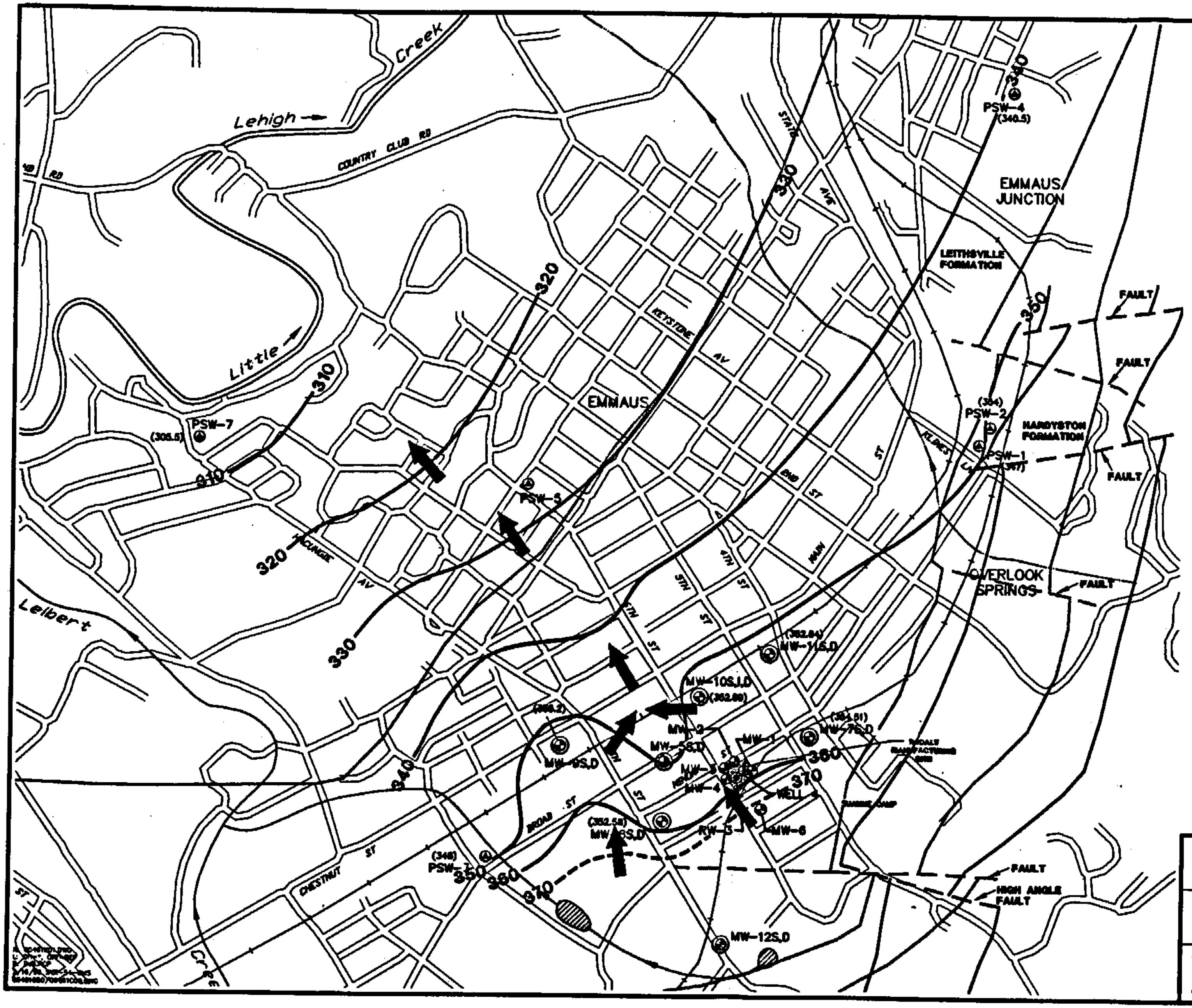
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE SHALLOW WELLS (~135 FT. DEPTH) AUGUST 19, 1996

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 20



LEGEND

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
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3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL). (NGVD OF 1929).
4. GWTS NOT PUMPING.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
1000' 0 1000'

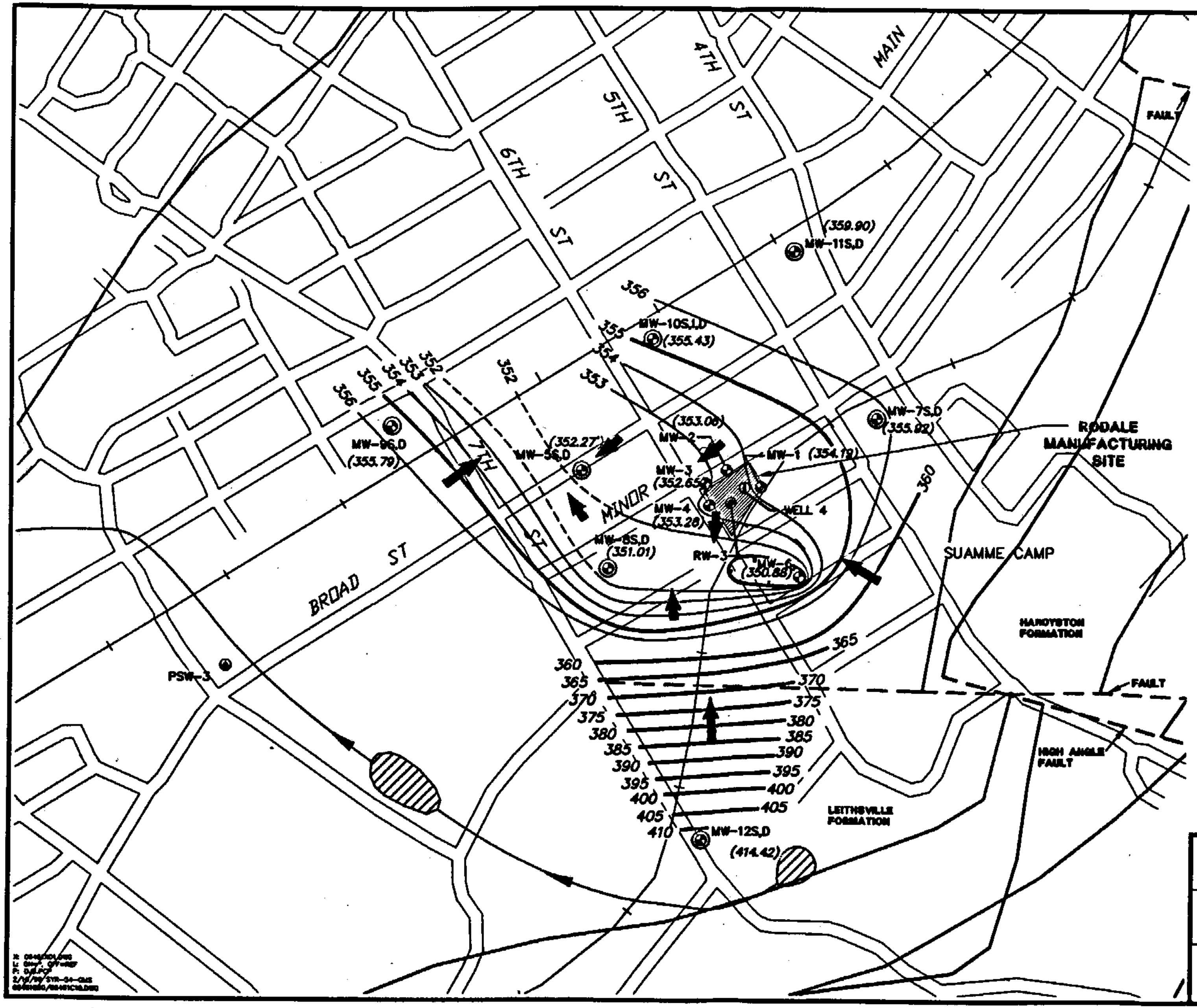
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE DEEP WELLS (~300 FEET DEPTH) AUGUST 19, 1996

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 21



LEGEND

- PUBLIC SUPPLY WELL
- MONITORING WELL CLUSTER
- SHALLOW MONITORING WELL
- FORMER DISPOSAL WELL
- RECOVERY WELL
- (355.92) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 355 POTENTIOMETRIC SURFACE ELEVATION CONTOUR (FT. AMSL), 5 FT. CONTOUR INTERVAL
- 352 POTENTIOMETRIC SURFACE ELEVATION CONTOUR (FT. AMSL), 1 FT. CONTOUR INTERVAL, DASHED WHERE INFERRED
- GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL), (NGVD OF 1929).
4. GWTS NOT PUMPING.
5. MW-12D POTENTIOMETRIC SURFACE WAS USED RATHER THAN MW-12S BECAUSE MW-12D SCREEN DEPTH IS COMPARABLE TO ON-SITE SHALLOW WELLS.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
500' 0 500'

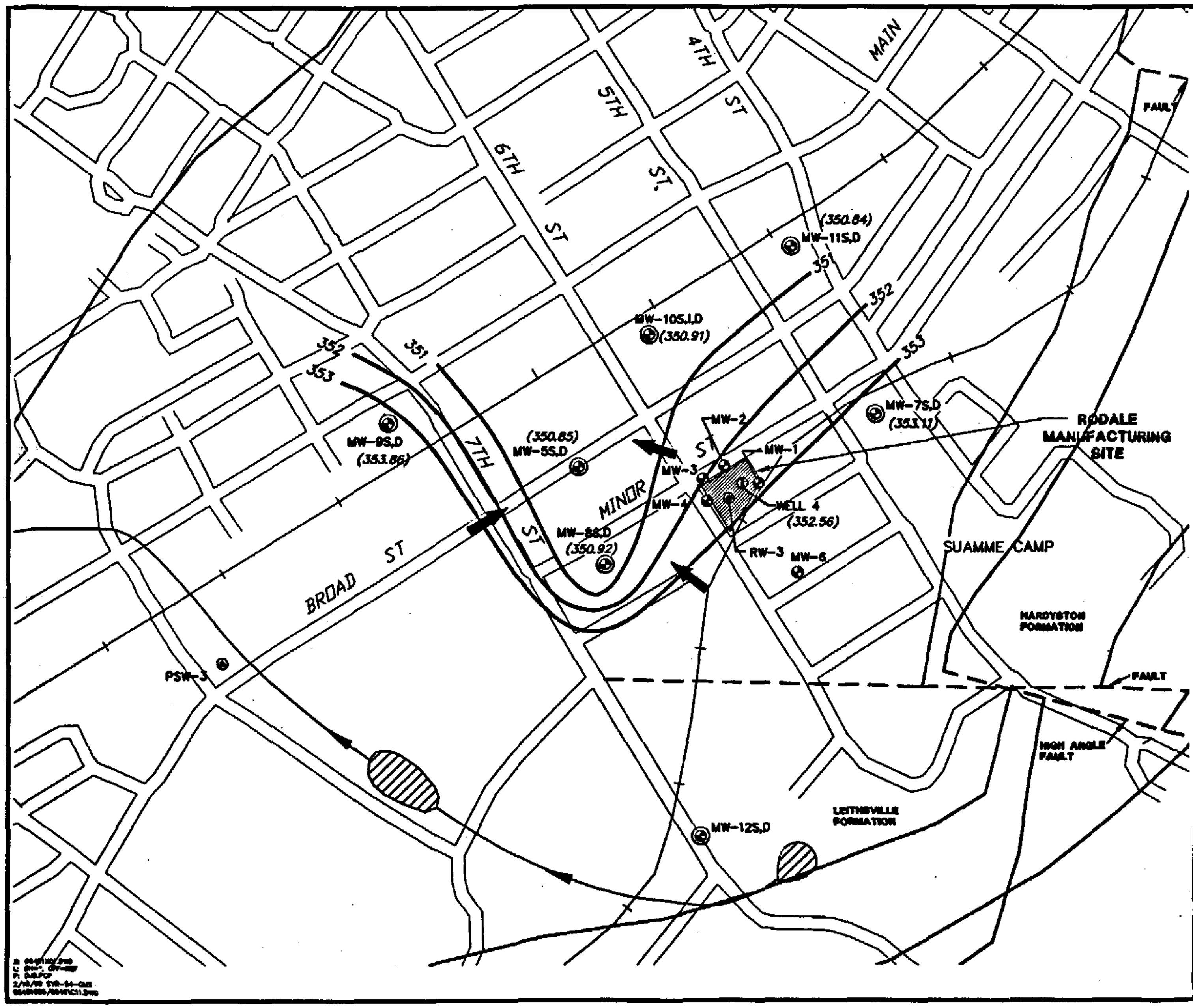
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE
SHALLOW WELLS (~135 FEET DEPTH)
OCTOBER 18, 1996

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
22



LEGEND

- ◬ PUBLIC SUPPLY WELL
- ⊕ MONITORING WELL CLUSTER
- ◍ SHALLOW MONITORING WELL
- ⦶ FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (360.85) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 351 —— POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL). DASHED WHERE INFERRED
- ⬅ GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

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3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL). (NGVD OF 1929).
4. GWTS NOT PUMPING.

REFERENCES:

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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:

500' 0 500'

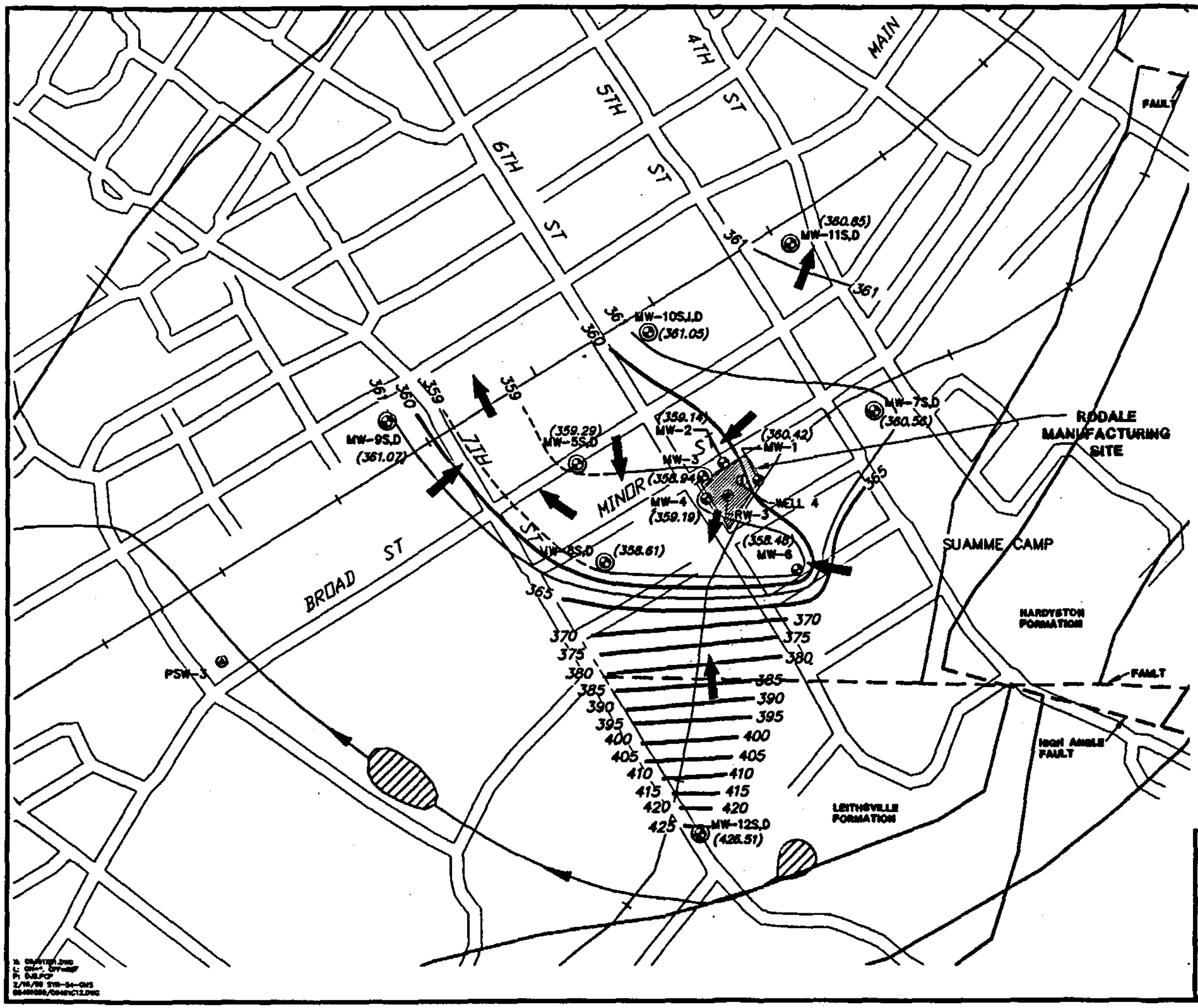
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE DEEP WELLS (~300 FEET DEPTH) OCTOBER 18, 1996

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 23



LEGEND

- PUBLIC SUPPLY WELL
- MONITORING WELL CLUSTER
- SHALLOW MONITORING WELL
- FORMER DISPOSAL WELL
- RECOVERY WELL
- (359.14) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 360 ——— POTENTIOMETRIC SURFACE ELEVATION CONTOUR (FT. AMSL), 5 FT. CONTOUR INTERVAL
- 361 ——— POTENTIOMETRIC SURFACE ELEVATION CONTOUR (FT. AMSL), 1 FT. CONTOUR INTERVAL, DASHED WHERE INFERRED
- ⬅ GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- ——— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- ——— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL), (NGVD OF 1929).
4. GWTS WAS OPERATING PERIODICALLY DURING THIS DATE.
5. MW-12D POTENTIOMETRIC SURFACE WAS USED RATHER THAN MW-12S BECAUSE MW-12D SCREEN DEPTH IS COMPARABLE TO ON-SITE SHALLOW WELLS.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
500' 0 500'

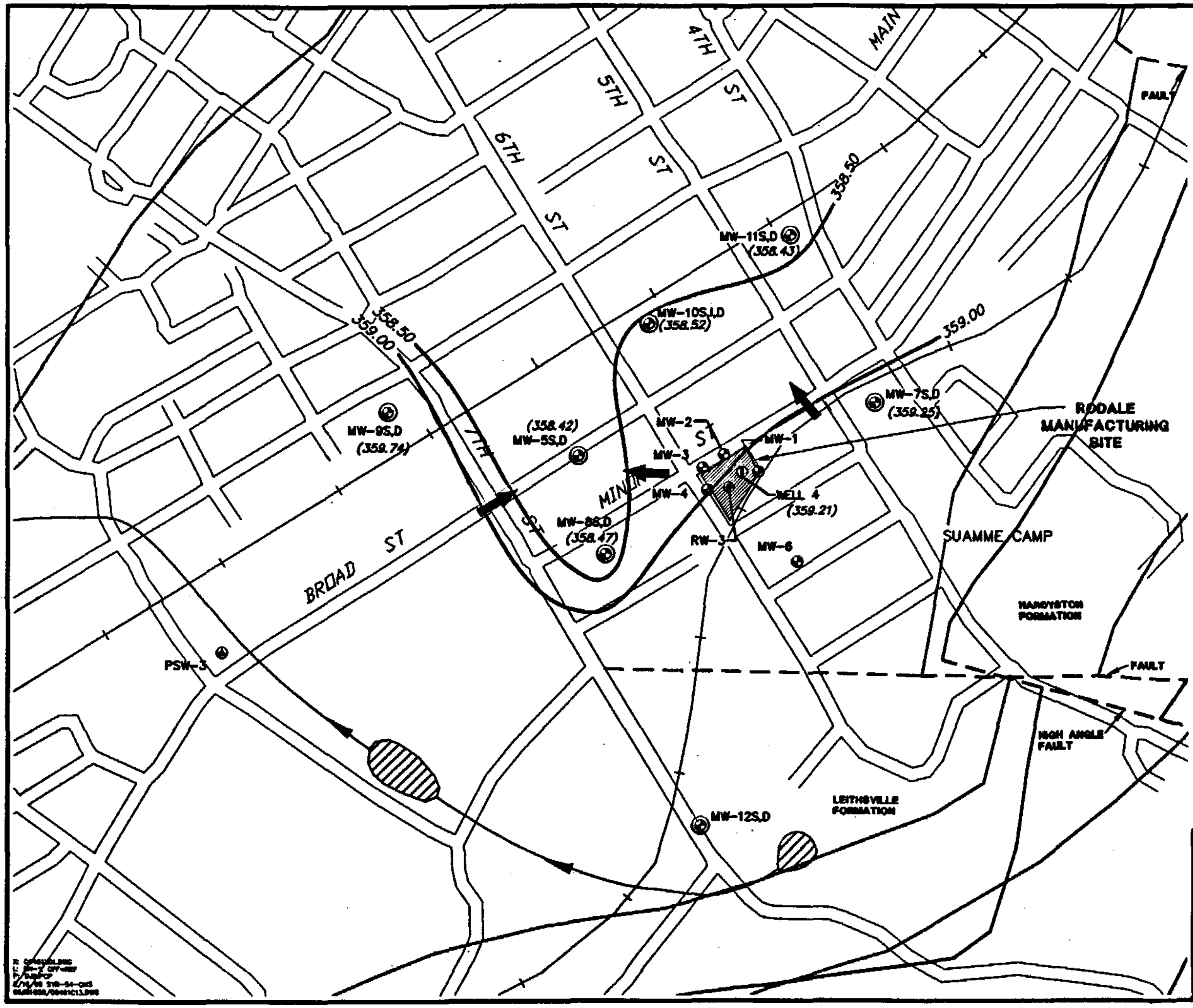
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE SHALLOW WELLS (~135 FEET DEPTH) JANUARY 7, 1997

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 24



LEGEND

- Ⓐ PUBLIC SUPPLY WELL
- ◎ MONITORING WELL CLUSTER
- ⊕ SHALLOW MONITORING WELL
- ⓘ FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (359.25) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 358.50 ─── POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL).
- ⬅ GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- ─── INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- ─── INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED

1.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLING LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.
3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL), (NGVD OF 1929).
4. GWTS WAS OPERATING PERIODICALLY DURING THIS DATE.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

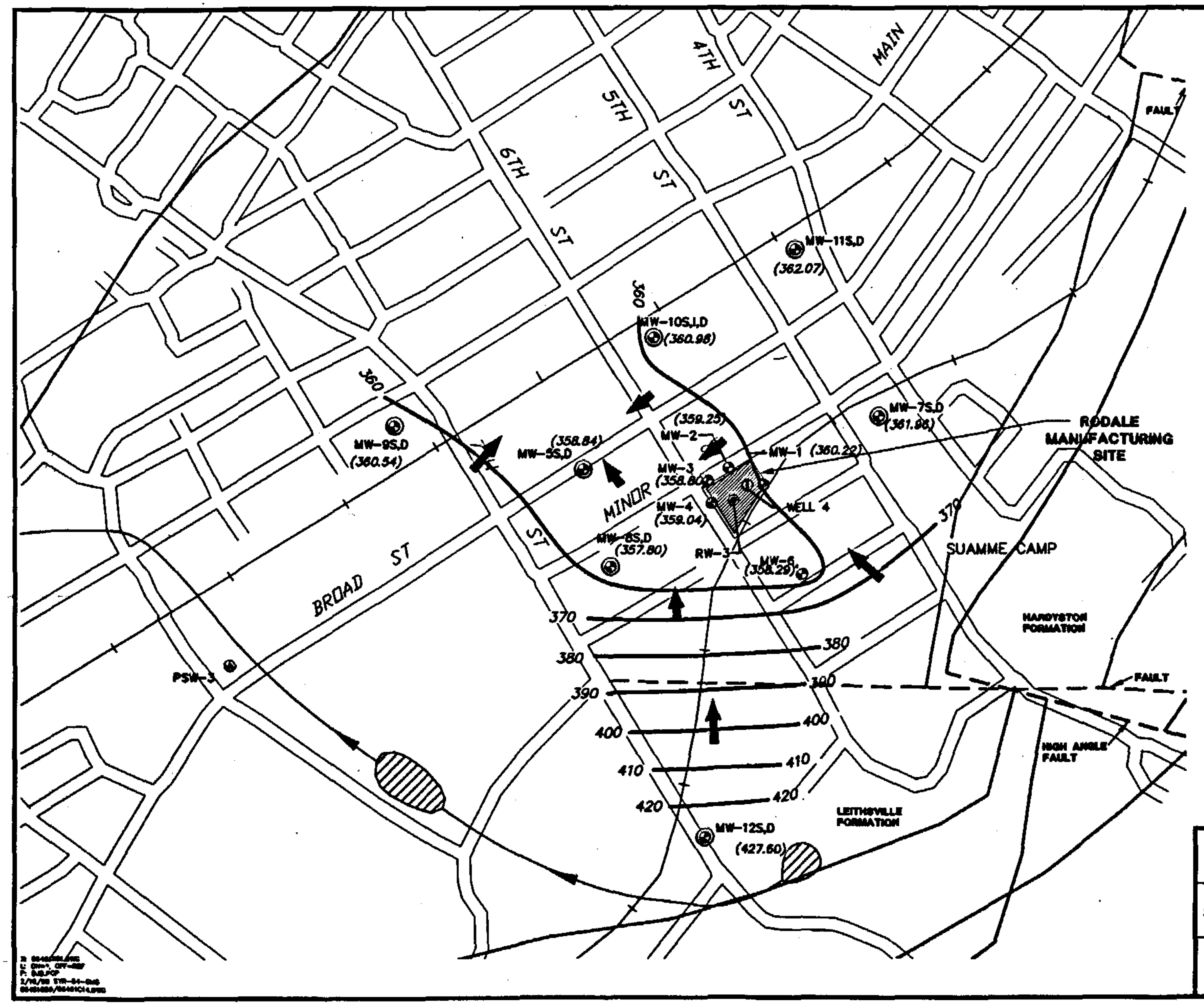
SCALE:
500' 0 500'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE
DEEP WELLS (~300 FEET DEPTH)
JANUARY 7, 1997

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 25



LEGEND

- PUBLIC SUPPLY WELL
- MONITORING WELL CLUSTER
- SHALLOW MONITORING WELL
- FORMER DISPOSAL WELL
- RECOVERY WELL
- (361.96) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 360 POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL).
- GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

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3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL), (NGVD OF 1929).
4. GWTS PUMPING CONDITIONS.
5. MW-12D POTENTIOMETRIC SURFACE WAS USED RATHER THAN MW-12S BECAUSE MW-12D SCREEN DEPTH IS COMPARABLE TO ON-SITE SHALLOW WELLS.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
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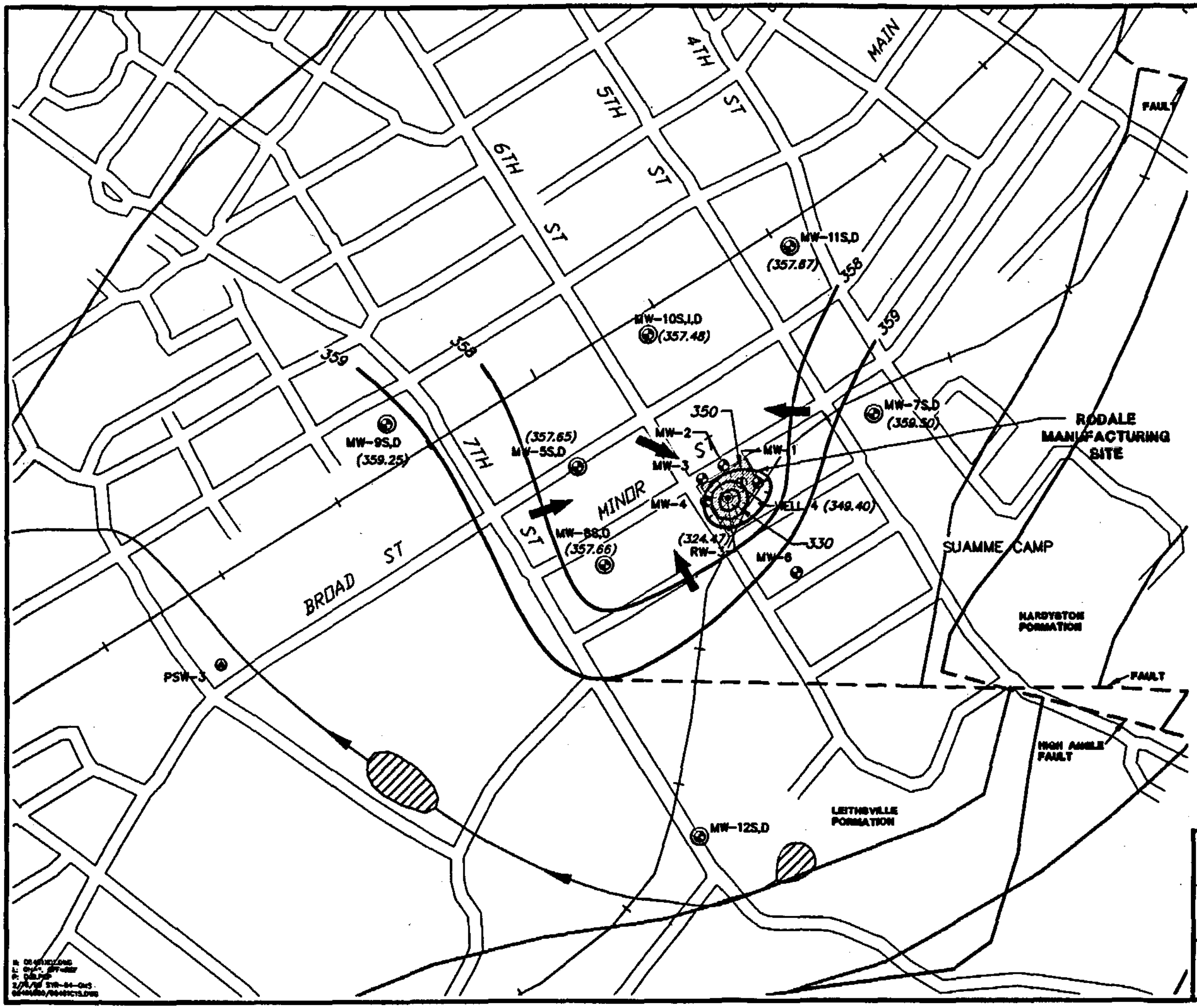
SCALE:
500' 0 500'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE
SHALLOW WELLS (~135 FEET DEPTH)
MARCH 11, 1997

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 26



LEGEND

- ⊕ PUBLIC SUPPLY WELL
- ◎ MONITORING WELL CLUSTER
- ⊕ SHALLOW MONITORING WELL
- ⦶ FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (359.50) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 359——— POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL)
- ⬅ GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- ——— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- ——— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

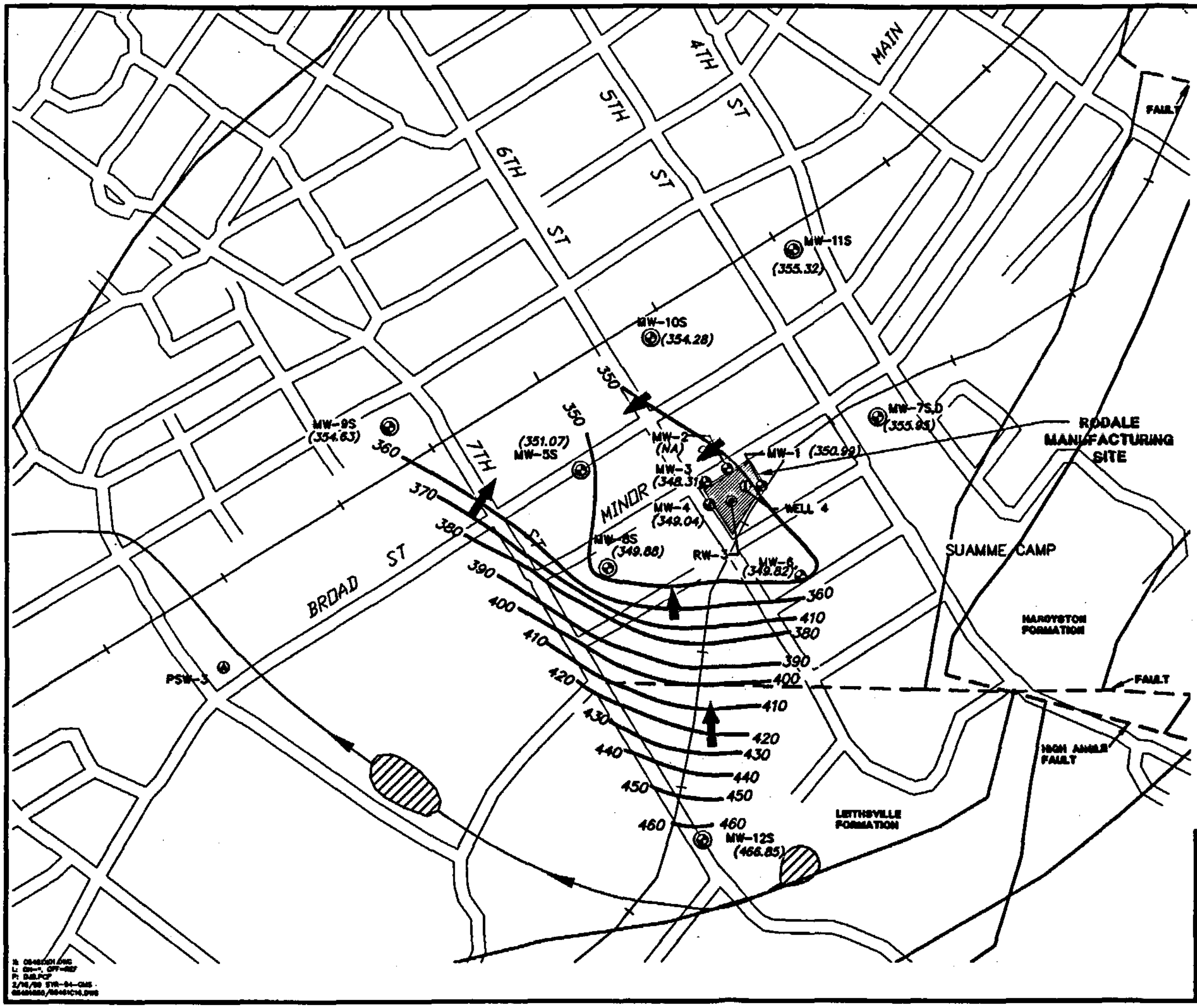
SCALE:
500' 0 500'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE DEEP WELLS (~300 FEET DEPTH) MARCH 11, 1997

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
27



LEGEND

- ⊗ PUBLIC SUPPLY WELL
- ◎ MONITORING WELL CLUSTER
- ● SHALLOW MONITORING WELL
- ⊙ FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (355.92) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 360—— POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL)
- ← GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

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3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL), (NGVD OF 1929).
4. GWTS PUMPING CONDITIONS.
5. MW-12D POTENTIOMETRIC SURFACE WAS USED RATHER THAN MW-12S BECAUSE MW-12D SCREEN DEPTH IS COMPARABLE TO ON-SITE SHALLOW WELLS.

REFERENCES:

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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
500' 0 500'

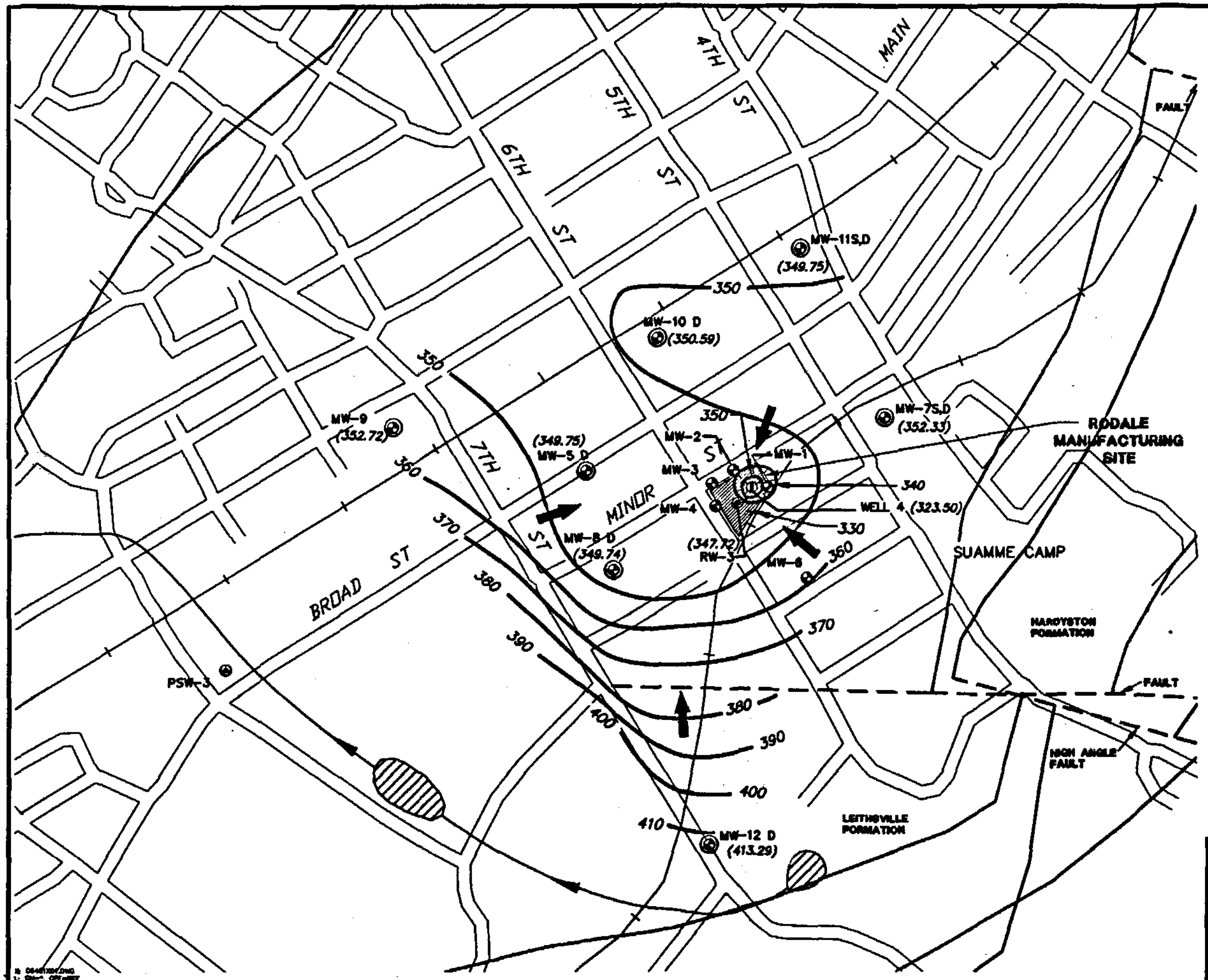
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE SHALLOW WELLS (~135 FEET DEPTH) OCTOBER 1, 1997

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 28



LEGEND

- ◎ PUBLIC SUPPLY WELL
- ◎ MONITORING WELL CLUSTER
- ● SHALLOW MONITORING WELL
- ① FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (352.33) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 350 —— POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL)
- ⬅ GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

NOTES:

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3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

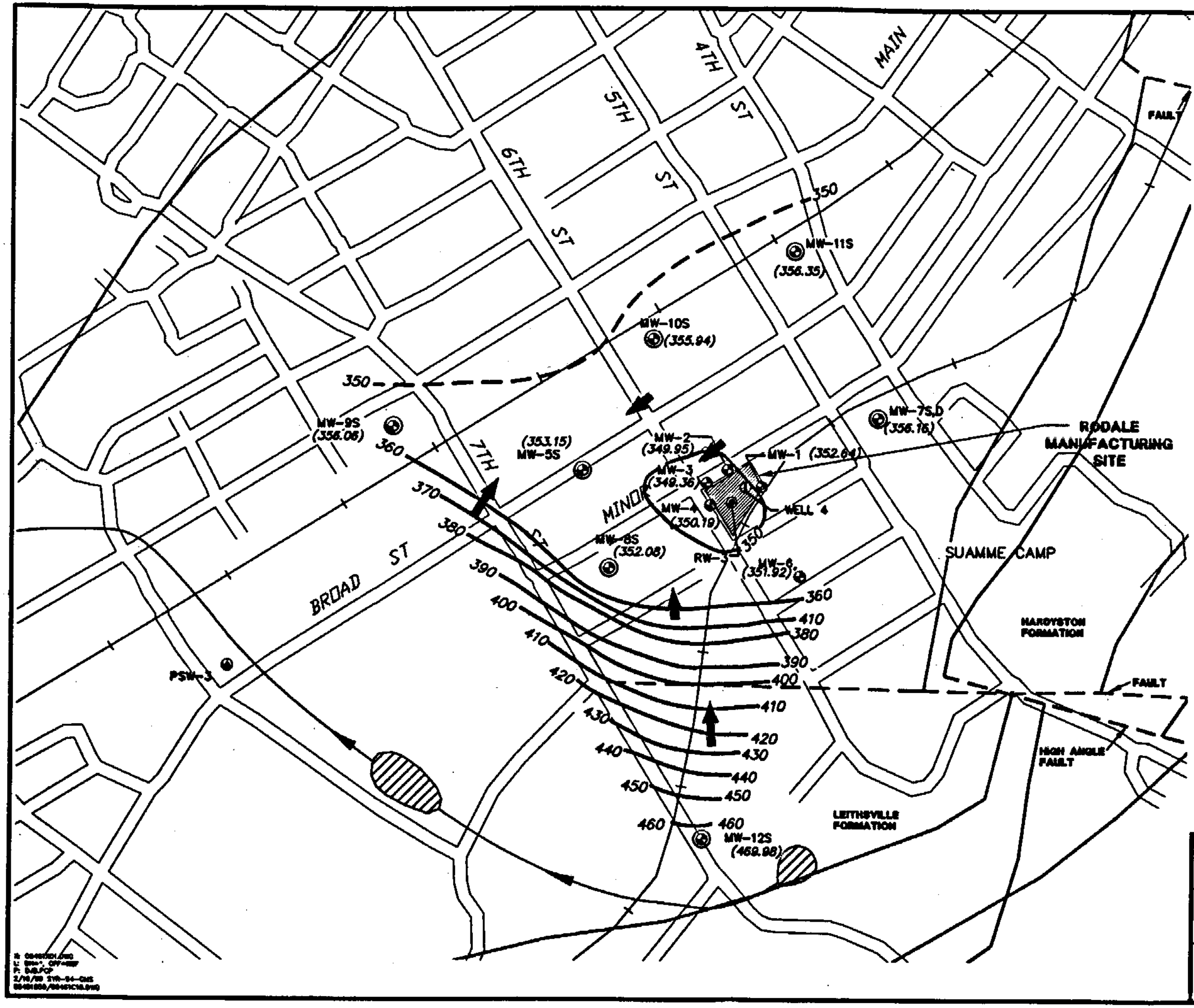
SCALE:
500' 0 500'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE
DEEP WELLS (~300 FEET DEPTH)
OCTOBER 1, 1997

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 29



LEGEND

- ⊙ PUBLIC SUPPLY WELL
- ◎ MONITORING WELL CLUSTER
- ⊕ SHALLOW MONITORING WELL
- ⦶ FORMER DISPOSAL WELL
- ● RECOVERY WELL
- (356.35) POTENTIOMETRIC SURFACE ELEVATION (FT. AMSL)
- 360—— POTENTIOMETRIC SURFACE ELEVATION CONTOUR LINE (FT. AMSL)
- ⬅ GENERALIZED HORIZONTAL HYDRAULIC GRADIENT DIRECTION
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (SLOTO)
- —— INTERPRETED GEOLOGIC CONTACT OR FAULT (WOOD)

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3. ALL VALUES IN FEET ABOVE MEAN SEA LEVEL (AMSL), (NGVD OF 1929).
4. GWTS PUMPING CONDITIONS.
5. MW-12D POTENTIOMETRIC SURFACE WAS USED RATHER THAN MW-12S BECAUSE MW-12D SCREEN DEPTH IS COMPARABLE TO ON-SITE SHALLOW WELLS.

REFERENCES:

1. PLATE 1, R.A. SLOTO et al. (1991), HYDROGEOLOGY AND GROUND-WATER FLOW IN THE CARBONATE ROCKS OF THE LITTLE LEHIGH CREEK BASIN, LEHIGH COUNTY, PA.; U.S.G.S. WATER-RESOURCE INVESTIGATION REPORT 90-4076.
2. PLATE 2, C.R. WOOD et al. (1972), WATER RESOURCES OF LEHIGH COUNTY, PA.; COMMONWEALTH OF PA. DEPT. OF ENVIRONMENTAL RESOURCES, WATER RESOURCE REPORT 31.
3. LOCATIONS OF FAULTS AND CONTACTS WERE DIGITIZED FROM LARGER SCALE MAPS AND ARE CONSIDERED APPROXIMATE ONLY.

SCALE:
500' 0 500'

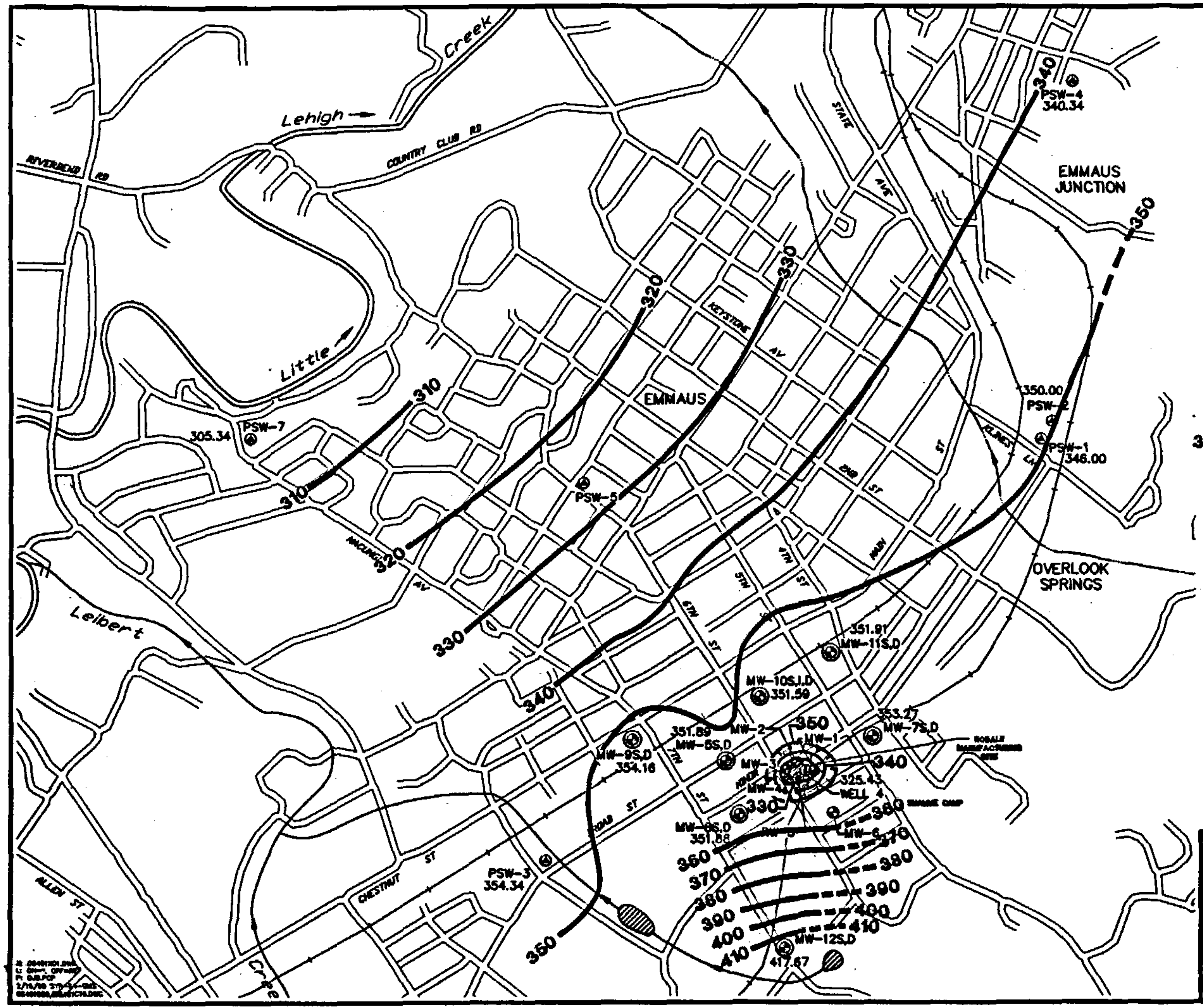
RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA

TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE SHALLOW WELLS (~135 FEET DEPTH) JULY 20, 1998

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 30



LEGEND

●	PUBLIC SUPPLY WELL
◎	MONITORING WELL CLUSTER
●	SHALLOW MONITORING WELL
◐	FORMER PRODUCTION/DISPOSAL WELL
●	RECOVERY WELL
354.16	POTENTIOMETRIC SURFACE ELEVATION (FEET)
350 ——	POTENTIOMETRIC SURFACE ELEVATION CONTOUR (FEET)

NOTES:

1. BASE MAP MODIFIED FROM GEO-ENVIRONMENTAL CONSULTANTS, INC. DRAWING ENTITLED "GROUNDWATER ELEVATION CONTOUR MAP SEPTEMBER 1993", FILE NUMBER EMM-REG.DWG, DATED 12/9/93.
2. MONITORING WELL, SOIL BORING, AND SURFACE SOIL SAMPLE LOCATIONS COMPLETED IN CONNECTION WITH THIS REMEDIAL INVESTIGATION HAVE BEEN SURVEYED. ALL OTHER LOCATIONS ARE APPROXIMATE.

SCALE:
1000' 0 1000'

RODALE MANUFACTURING SITE
EMMAUS, PENNSYLVANIA
TECHNICAL IMPRACTICABILITY EVALUATION

POTENTIOMETRIC SURFACE
DEEP WELLS (~300 FOOT DEPTH)
JULY 20, 1998

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
31

Attachment 1

Impact of Matrix Diffusion on Containment Fate and Transport in Fractured Bedrock at the Rodale Manufacturing Site

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

Impact of Matrix Diffusion on Contaminant Fate and Transport in Fractured Bedrock at the Rodale Manufacturing Site

Prepared for: Square D Company

Prepared by: Dr. B.H. Kueper

Date: August 21, 1998

Executive Summary

The purpose of this report is to examine the impact of matrix diffusion on the fate and transport of trichloroethylene (TCE) in fractured bedrock at the Rodale Manufacturing Site located in Emmaus, PA. Use is made of an exact analytical solution which solves for solute concentration in both open fractures and the rock matrix. The model adopts a set of parallel, equally-spaced fractures subject to a uniform groundwater velocity field.

The first set of presented simulations assigns a constant TCE source concentration of 285 ppm at the inlet to a 100 m long flow system. After approximately 30 years, the matrix blocks along the entire flowpath are nearly saturated with TCE as a result of inward matrix diffusion from fractures. The fracture spacing, fracture aperture, matrix porosity, matrix dry bulk density, and matrix fraction organic carbon are based on average values presented by BBL (1998).

The second set of presented simulations assumes that a pump-and-treat system has been installed 100 m downgradient of the TCE source, and that the source of TCE has been removed. This is equivalent to the injection of clean water at the inlet to the flow system after 30 years of exposure to a source of TCE. The second set of simulations is also based on the average bedrock characterization parameters presented by BBL (1998). The simulations indicate that the concentration of TCE in the open fractures is reduced to below 1 ppb along the entire flow path after approximately 30 years of clean water injection. Significantly higher concentrations of TCE persist in the matrix blocks, however, with the highest concentrations occuring at the center of the blocks.

It should be pointed out that the analytical solution adopted for this study cannot capture all of the complexities of the bedrock flow system at the Rodale site. In addition, average bedrock characterization data were employed in this study, rather that the full range of measured parameters. It should therefore be expected that there will be portions of the flow system exhibiting both shorter and longer diffusion time-scales than those presented here.

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1.0 Introduction

The purpose of this document is to examine the impacts of matrix diffusion on solute fate and transport in bedrock at the Rodale Manufacturing site located in Emmaus, PA. The bedrock at this site belongs to the Leithsville Formation, and consists predominantly of fine-grained, thin bedded dolomites that grade locally into massive beds of blue gray dolomite. The bedrock has a measured average matrix porosity of approximately 6.5% (BBL, 1998), suggesting that matrix diffusion will influence the fate and transport of solutes dissolved in groundwater.

Matrix diffusion refers to the process whereby solutes dissolved in groundwater diffuse either from open fractures into the rock matrix, or from the rock matrix into open fractures. The term 'matrix' refers here to the blocks of rock separating fractures. The direction of diffusion will depend on the direction of the concentration gradient. When contaminants are initially introduced into fractures, for example, a strong concentration gradient exists from the open fractures to the uncontaminated rock matrix, bringing about diffusion of contaminants into the matrix. This process will continue until either the contaminant storage capacity of the matrix is met, or the source of contamination in the fractures is exhausted. Once the source of contamination is removed from the fractures, the concentration gradient will be from the matrix to the fractures, bringing about diffusion of contaminants back out of the matrix and into the fractures. The matrix diffusion process was first examined in a contaminant hydrogeology context by Foster (1975), and has since been examined by a number of authors including Goodall and Quigley (1977), McKay et al. (1993), Germain and Frind (1989), and Pankow and Cherry (1996).

One implication of matrix diffusion is that the majority of dissolved and sorbed phase contamination in bedrock may be located in the rock matrix, not in the open fractures. Because the open fractures typically have a higher permeability than the rock matrix, it follows that the primary groundwater flow pathways are through the fractures, not through that portion of the bedrock where the majority of contaminants may be stored. While the open fractures can be thought of as the primary pathways for groundwater flow, the rock matrix can be thought of as the primary reservoir for contaminant storage.

A second implication of matrix diffusion is that the rate of dissolved plume migration in fractured bedrock may be significantly less than the rate of groundwater flow. Matrix diffusion acts as a contaminant sink, continuously removing solutes from groundwater flowing through fractures. This can be thought of as an attenuation process which manifests itself in a manner similar to that of sorption to grain surfaces. In other words, matrix diffusion results in the contaminant velocity being less than the groundwater velocity. This is one reason why contaminant plumes in fractured bedrock at certain sites have not traveled as far in the hydraulically downgradient direction as would be predicted from consideration of groundwater velocities alone.

A third implication of matrix diffusion is that the time required to clean-up fractured bedrock will be governed by the rate at which contaminants can diffuse back out of the rock matrix. Even if clean groundwater is flushed through open fractures, this groundwater will become contaminated by solutes diffusing back out of the rock matrix and into the fractures. This diffusion out of the rock matrix will continue until all contamination in the matrix has been depleted.

A fourth implication of matrix diffusion is that residual and pooled DNAPL present in rock fractures will dissolve directly (by diffusion) into the rock matrix, as well as into groundwater flowing through the fractures. In certain bedrock environments, the life-span of residual and pooled DNAPL is governed by the rate at which the DNAPL dissolves directly into the rock matrix, not the rate at which it dissolves into flowing groundwater. In deposits such as fractured clay, for example, the lifespan of DNAPL in fractures can be relatively short because of the high contaminant storage capacity of the clay matrix.

This report will address the third implication described above, with the specific objective of examining solute concentrations both in fractures and the rock matrix.

2.0 Theory

The mathematical model employed in this study is based on the work of Sudicky and Frind (1982) and addresses contaminant transport through a set of parallel, equally spaced fractures. The model accounts for advective-dispersive solute transport in the fractures subject to diffusion into the matrix, sorption to the fracture walls, sorption within the matrix, and first-order decay of the solute. Unidirectional, steady-state groundwater flow is assumed to be occurring through the set of parallel fractures, with no advective component of flow in the rock matrix.

The governing equation for contaminant transport in the fractures is given by:

$$\frac{\partial c}{\partial t}+\frac{v}{R}\frac{\partial c}{\partial z}-\frac{D}{R}\frac{\partial^2 c}{\partial z^2}+\lambda c-\frac{\phi D'}{bR}\left.\frac{\partial c'}{\partial x}\right|_{x=b}=0 \qquad (1)$$

where c is the concentration of contaminant in the fractures, t is time, v is the average linear groundwater velocity in the fractures, D is the coefficient of hydrodynamic dispersion in the fractures, z is the distance of travel along the fractures, λ is the contaminant decay constant, ϕ is the matrix porosity, b is equal to $e/2$ where e is the fracture aperture, D' is the effective diffusion coefficient for the matrix, c' is the concentration of contaminant in the matrix, and x is the distance into the matrix. The fracture retardation factor, R, which accounts for sorption to the fracture walls, is represented by:

$$R=1+\frac{K_f}{b} \qquad (2)$$

where K_f is the mass of solute per unit fracture wall area divided by the concentration of solute in solution assuming a linear sorption isotherm.

Contaminant transport in the matrix is represented by:

$$\frac{\partial c'}{\partial t} - \frac{D'}{R'}\frac{\partial^2 c'}{\partial x^2} + \lambda c' = 0 \qquad (3)$$

where R' is the retardation factor representing sorption of solute to grain surfaces within the matrix, calculated as:

$$R' = 1 + \frac{\rho_b}{\phi} K_m \qquad (4)$$

where ρ_b is the dry bulk density of the matrix, and K_m is the distribution coefficient for the matrix calculated as $K_{oc} f_{oc}$ where K_{oc} is the organic carbon partition coefficient for the solute of concern, and f_{oc} is the fraction organic carbon of the matrix.

Equations (1) and (3) are coupled through the diffusive flux crossing the fracture/matrix interface, and the through the fact that $c = c'$ at $x = b$. The closed-form analytical solution representing the solution to the above set of governing partial differential equations is described further by Sudicky and Frind (1982). The model assumes that a constant concentration source is maintained at the inflow end to the set of parallel fractures (i.e., at $z = 0$). The model solves for the concentration distribution in both the open fractures and the rock matrix for any time and spatial location of interest.

3.0 Model Simulations

3.1 Non-pumping Conditions

Input Parameters

The first set of numerical simulations illustrates that trichloroethylene (TCE) will diffuse into a porous rock matrix while being simultaneously transported through fractures. A 100 m long set of parallel fractures with a constant source of TCE at $x = 0$ will be examined. The constant source of TCE at the inlet to the system is assumed to be in the form of a dense, non-aqueous phase liquid (DNAPL). BBL (1998) report that TCE concentrations in bedrock at the Rodale site range from 20 ppb to 570 ppm. The midpoint of this range (285 ppm) was used as the source concentration. The initial condition at $t = 0$ is zero concentration of TCE throughout the fractures and matrix. The simulations span a time period of 30 years, consistent with the fact that TCE was first used at the site in approximately 1959 (BBL, 1998).

BBL (1998) report an average fracture spacing of 0.262 m and an average fracture aperture of 450 microns for the Rodale site. These values have been adopted for all simulations presented in this report. The matrix porosity is set to 0.065, which represents the average value reported by BBL (1998). The average matrix dry bulk density (2.60 g/cc) and the average rock matrix fraction organic carbon (0.0012) reported by BBL (1998) have been adopted to yield a matrix retardation factor for TCE of 7.05. A TCE organic carbon partition coefficient of 126 ml/g (Pankow and Cherry, 1996) was utilized to calculate the retardation factor using equation (4).

All simulations incorporated a fracture dispersivity of 0.3 m, a matrix tortuosity of 0.2, a free-solution TCE diffusion coefficient of 10.0E-10 m^2/s (Pankow and Cherry, 1996), a hydraulic gradient of 0.010, no sorption onto fracture walls, and no solute degradation. The matrix effective diffusion coefficient is calculated in the model as the product of the free-solution diffusion coefficient and the matrix tortuosity.

A dispersivity of 0.3 m is considered reasonable for individual, rough-walled fractures (Pankow and Cherry, 1996). The fracture dispersivity influences the degree of dispersion occurring in the open fractures, but does not exert a great influence on the rates of contaminant diffusion both into and out of the rock matrix. A matrix tortuosity of 0.2 is reasonable for bedrock exhibiting a moderate to high matrix porosity (Pankow and Cherry, 1996). A low value of tortuosity results in slower rates of diffusion in the matrix, while a high value of tortuosity implies that diffusion paths are relatively unimpeded by the presence of the solids comprising the rock matrix, leading to faster rates of diffusion. Tortuosity values range from 0 to 1, with 0 corresponding to a medium in which diffusion cannot take place, and 1 corresponding to an open solution containing no porous medium.

Sorption onto fracture walls is not included in this analysis since it represents a minor component of the overall attenuation of solute transport in bedrock. In other words, the main process governing solute transport in fractures at the Rodale site is matrix diffusion, not sorption along fracture walls. For the contaminant of interest in this report (TCE), sorption to fracture walls is expected to be small.

The hydraulic gradient of 0.010 is considered representative of hydraulic conditions within bedrock at the Rodale site (BBL, 1998). This hydraulic gradient was used in conjunction with the fracture aperture to obtain a groundwater velocity in the fractures as follows:

$$v = -\frac{e^2 \rho g}{12\mu} \nabla h \qquad (5)$$

where v is the groundwater velocity of interest, e is the fracture aperture, ρ is the density of groundwater, g is the acceleration due to gravity, μ is the viscosity of groundwater, and ∇h is the hydraulic gradient in the fracture. Table 1 presents a summary of the input parameters utilized to simulate non-pumping conditions.

Table 1 - Model Input Parameters

Parameter	Value
Source concentration	0.285 kg/m^3
Fracture aperture	450 microns
Fracture spacing	0.262 m
Matrix porosity	0.065
Matrix dry bulk density	2.60 g/cc
Matrix fraction organic carbon	0.0012
Hydraulic gradient	0.010
Groundwater velocity	0.00165 m/s
TCE organic carbon partition coefficient	126 ml/g
TCE matrix retardation factor	7.05
TCE free solution diffusion coefficient	10.0E-10 m^2/s
Matrix tortuosity	0.2

Results

Figure 1 presents a plot of TCE concentration versus position in the matrix at a distance of 10 m downstream of the source for times of 10, 20, and 30 years. At a time of 10 years, concentrations within the matrix block range from approximately 190 ppm in the center of the block, to approximately 285 ppm at the edges. The fact that the TCE concentration is 285 ppm at the edges of the matrix block implies that the TCE concentration in the fractures is also 285 ppm at this location. After 30 years, the matrix block is nearly saturated with TCE at a concentration of approximately 285 ppm. The figure clearly illustrates that solutes migrating through open fractures will diffuse into a porous rock matrix.

Figure 2 presents a plot of TCE concentration versus position in the matrix at a distance of 50 m downstream of the TCE source. As in the previous figure, TCE diffusion occurs from the open fractures into the rock matrix, with the matrix block nearly saturated with TCE at a time of 30 years. Figure 3 presents a plot of TCE concentration versus position in the matrix at a distance of 100 m downstream of the source for times of 10, 20, and 30 years. As in the previous two figures, the matrix block becomes nearly saturated with TCE at a time of 30 years.

The fact that the sets of concentration profiles in Figures 1 through 3 are similar to each other follows from the fact that high concentrations of TCE are rapidly propagated through the open fractures. This is expected in a fracture-controlled flow system where the fracture apertures are relatively high (450 microns). Aqueous phase TCE present in the fractures is the source of TCE for molecular diffusion into the rock matrix. It should also be pointed out that the simulation results presented in Figures 1 through 3 utilize average properties measured for the Rodale Site. Because parameters such as fracture aperture, fracture spacing, and matrix porosity are spatially variable at the site, there will be portions of bedrock exhibiting both shorter and longer diffusion time scales than those presented here.

3.2 - Pumping Conditions With No DNAPL Source

Input Parameters

To examine the time-scales required for reverse diffusion back out of the rock matrix, a series of simulations was completed assuming that the source of TCE has been removed from the inlet to the system after 30 years. This set of simulations assigns a source concentration of zero at the inlet after 30 years of exposure to a source concentration of 285 ppm. This corresponds to a pump-and-treat system placed 100 m downstream of the source, with injection of clean water at the location of where the TCE source was previously assigned. Other than the source concentration, all input parameters are identical to those presented in Table 1.

Results

Figure 4 presents a plot of TCE concentration in the fractures versus distance from the location of clean water injection for times of 10 and 20 years. A time of zero in Figure 4 corresponds to the start of pump-and-treat operations. The figure shows that concentrations in the fractures increase with distance downstream of the location of water injection due to reverse diffusion of TCE back out of the rock matrix. After 30 years, the concentration of TCE in the fractures has been reduced to below 1 ppb for all locations along the flow path (plot not shown).

Figure 5 presents a plot of TCE concentration versus position in the matrix blocks at a distance of 50 m downstream of the location of water injection. It is clear that the highest concentrations are in the center of the matrix blocks, giving rise to a concentration gradient resulting in outward diffusion. After 10 years of pumping, the concentration in the center of the matrix blocks is on the order of 100,000 ppb, while the concentration at the edges of the matrix blocks is on the order of 3,500 ppb. The concentration at the edge of the matrix blocks equals the concentration in the open fractures which bound the blocks. After 30 years of clean water injection, the concentrations in the center of the matrix blocks is still on the order of 8,000 ppb, but the concentration at the edge of the blocks (and in the open fractures at this location) is less than 1 ppb.

As discussed above, the presented simulations have adopted the average bedrock properties reported by BBL (1998). While the current set of simulations suggests that concentrations in the open fractures will be reduced to less than 1 ppb along the 100 m flowpath within 30 years, the use of the full range of bedrock parameters presented by BBL (1998) would result in cases of both quicker and longer clean-up times than those presented here.

References

Blasland, Bouck, & Lee, Inc., 1998. Remedial Investigation Report, Rodale Manufacturing Site, Emmaus, Pennsylvania. Prepared for Square D Company.

Foster, S.S.D., 1975. The chalk groundwater tritium anomaly - a possible explanation. Journal of Hydrology, 25, pp. 159-165.

Germain, D. and Frind, E.O., 1989. Modelling of contaminant migration in fracture networks: Effects of matrix diffusion. In Proceedings, International Symposium on Contaminant Transport in Groundwater, University of Stuttgart, Germany, April.

Goodall, D.C. and Quigley, R.M., 1977. Pollutant migration from two sanitary landfill sites near Sarnia, Ontario. Canadian Geotechnical Journal, 14, pp. 223-236.

McKay, L.D., Gillham, R.W., and Cherry, J.A., 1993. Field experiments in a fractured clay till, 2: Solute and colloid transport. Water Resources Research, 29, pp. 3879-3890.

Pankow, J.F. and Cherry, J.A. (Editors), 1996. Chlorinated Solvents and Other DNAPLs in Groundwater, Waterloo Press, Portland, OR.

Sudicky, E.A. and Frind, E.O., 1982. Contaminant transport in fractured porous media: Analytical solutions for a system of parallel fractures. Water Resources Research, 18, pp. 1634-1642.

Figure 1 - TCE Concentration vs Position in Matrix
(x = 10 m)

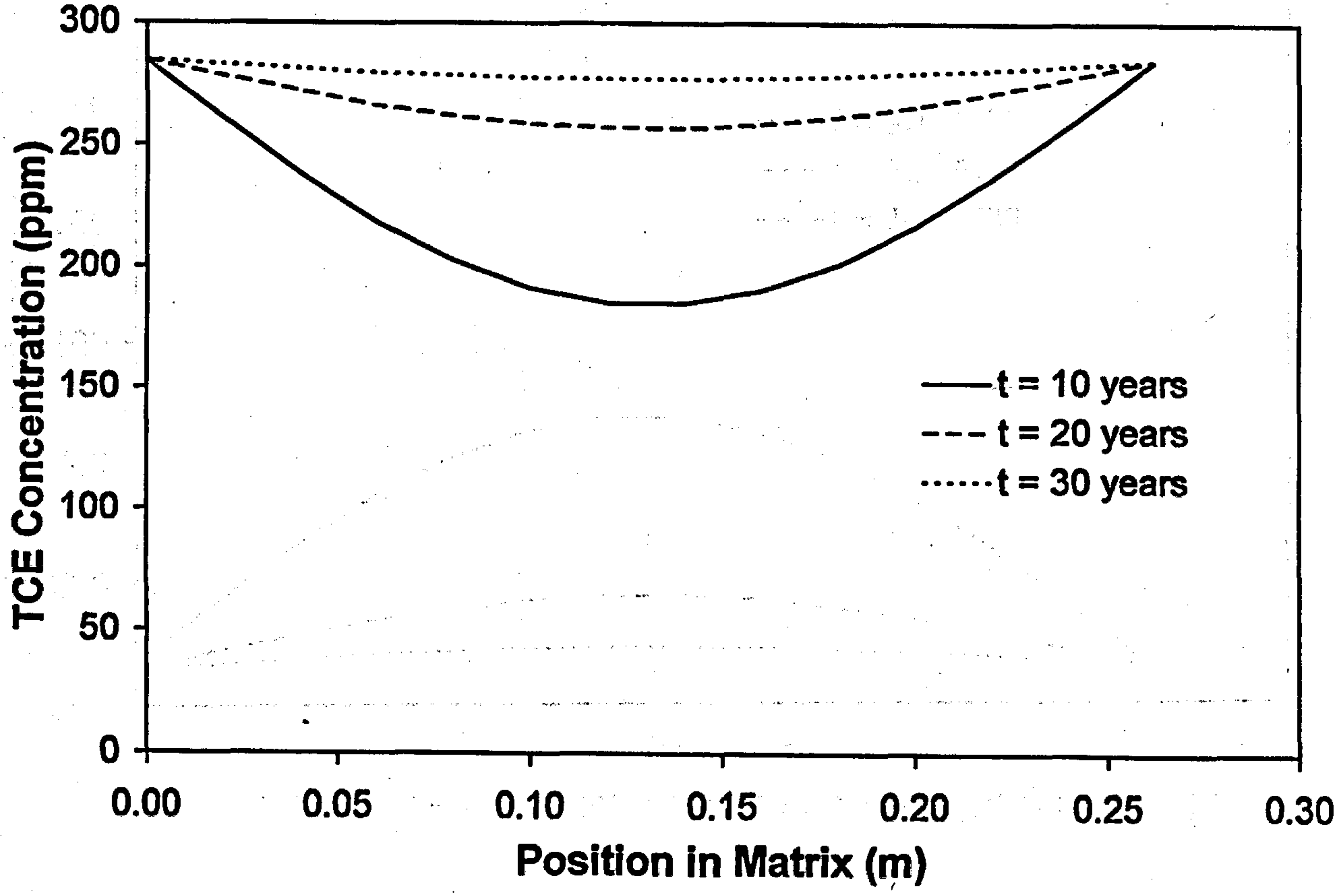

Figure 2 - TCE Concentration vs Position in Matrix
(x = 50 m)

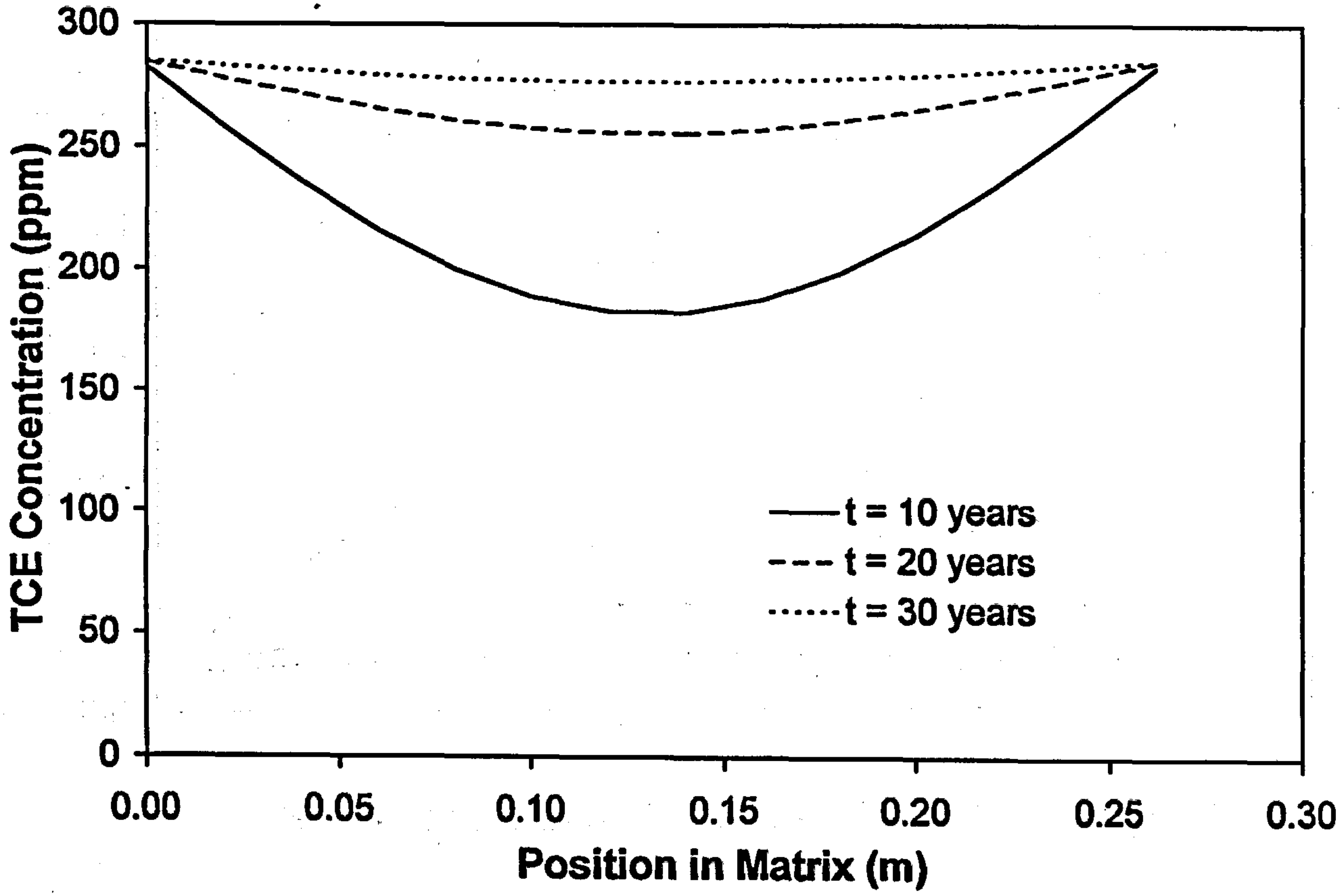

Figure 3 - TCE Concentration vs Position in Matrix
(x = 100 m)

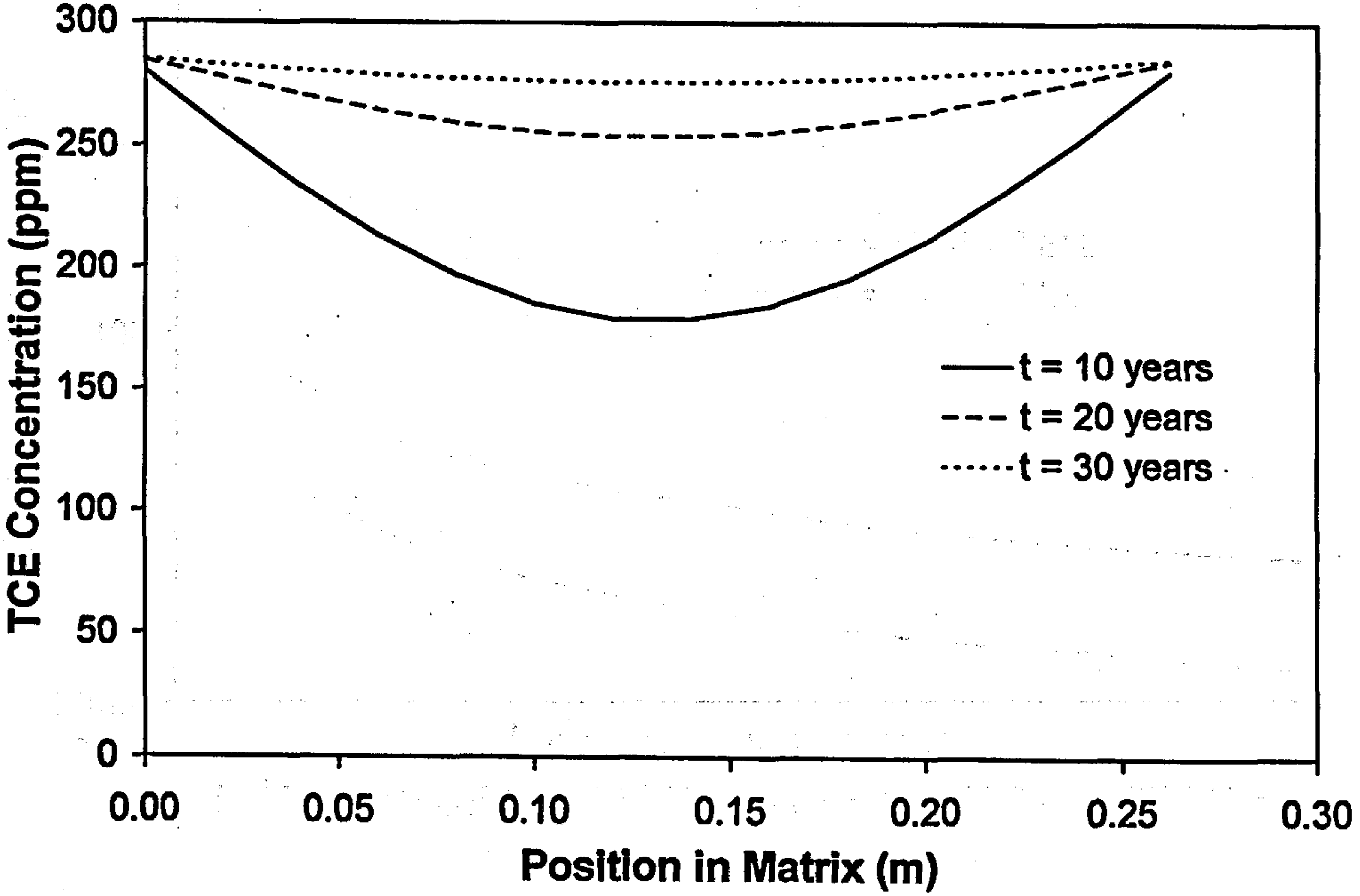

Figure 4 - TCE Concentration in Fractures vs Distance
(Time since P/T started)

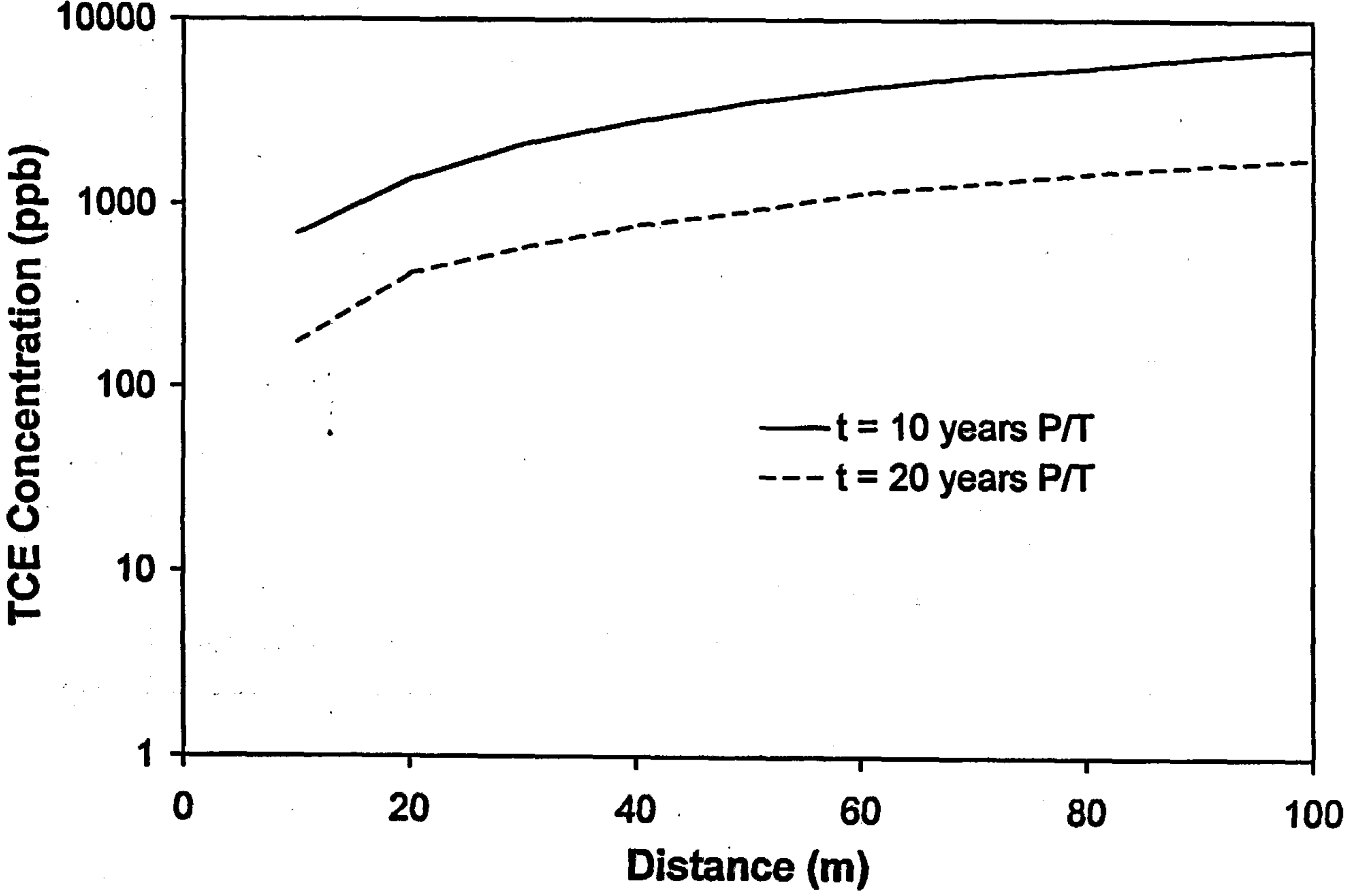

Figure 5 - TCE Concentration vs Position in Matrix
(x = 50 m, time since P/T started)