SITE CHARACTERIZATION REPORT

VOLUME I

(Report)

for

General Switch Site
Middletown, New York

June 30, 1993

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EXECUTIVE SUMMARY

The Wallkill Well Field Site is located in the Township of Wallkill in Orange County, New York. The Site is adjacent to Highland Avenue and Industrial Place in Wallkill, in an area called the Highland Avenue Extension.

In 1983, the residential well located on 320 Highland Avenue was identified by the New York State Department of Health (NYSDOH) as being contaminated with tetrachloroethylene. Subsequent investigations by the United States Environmental Protection Agency (USEPA) and the New York State Department of Environmental Conservation (NYSDEC) identified several residential wells in the area surrounding the Site as being contaminated with over 50 parts per billion (ppb) of tetrachloroethylene, which at that time was the Maximum Concentration Level (MCL) allowable in drinking water.

On November 1983, a temporary water line was constructed to supply the affected residents on Highland Avenue. On May 1, 1984, General Switch provided a permanent underground water main down Highland Avenue that tapped the water from the Wallkill municipal water supply.

In addition to the regulatory agency studies, a study conducted by Fred C. Hart at the Site identified tetrachloroethylene-contaminated soils at three locations designated "hot spots" on the property at 20 Industrial Place owned by the General Switch Corporation, a distance of 200 feet from the 320 Highland Avenue residential well.

This report presents the findings and conclusions of the site investigation conducted between 1992-1993, by Shakti Consultants with guidance, oversight, logistical assistance and report review from Jacobs Environmental, Inc. The objective of the investigation was to determine the extent of the soil and groundwater contamination in the vicinity of the General Switch property and to obtain sufficient data to enable an evaluation of remedial alternatives.

The site investigation included a review and assessment of available data on past studies, a field exploration program and data reduction and analysis. The field exploration program included soil borings; groundwater monitoring wells; geophysical studies; pump tests; well logging; and sampling of soils, groundwater, surface water/surface sediment, sewer water/sediments, and air. Additionally, two pilot studies were conducted as part of the investigation; a soil vapor extraction study and the operation of an air stripper used to treat groundwater which was generated during testing activities. On-site analysis as well as laboratory analysis was conducted. The on-site analysis was conducted with a Photovac and the laboratory analysis was conducted by NYTEST Environmental, a CLP laboratory.

The major findings of the site investigation are summarized below:

- The stratigraphy of the site is a silty glacial till overlaying a sandstone and shale bedrock formation. The glacial till ranges from 7 to 108 feet thick under the site. The strike of bedding for the bedrock is northeast-southwest and the regional dip is 16-40 degrees northwest.

- Local groundwater flow in the unconsolidated overburden and bedrock is generally from north to south.

- Volatile organic compounds (VOCs), particularly tetrachloroethylene, were the primary contaminants found in samples collected at the Site. The VOC contamination is likely to have originated as a surface release. The migration of the VOCs is likely to have occurred through percolation of rainwater and groundwater flow through the overburden and fractured bedrock.

- Soil contamination was found at three "hot spots" on the General Switch property. The levels of tetrachloroethylene in the soil samples collected ranged from not detected to 5,500 parts per million (ppm).

- Groundwater contamination in the form of free product of tetrachloroethylene was detected in the residential well W-30, located at 320 Highland Avenue. A product only recovery pump was installed in well W-30 to remove the tetrachloroethylene as an interim remedial measure.

- Groundwater contamination in the unconsolidated (glacial till) shallow aquifer was confirmed. The plume appears to be concentrated from north of the General Switch building, through the southern corner of the parking lot to Industrial Place Extension and extends into the wetlands south of the property.

- Groundwater contamination in the bedrock aquifer was confirmed. The contaminated groundwater plume in the bedrock appears to have a linear shape which trends east to west in a 150-foot-wide zone approximately 700 feet long.

- The results from the pilot studies indicated that soil vapor extraction and treatment is effective at the site; similarly, contaminated groundwater was successfully treated with the air stripper.

Several recommendations are proposed based on the findings of the site investigation:

- Continue to remove free product from the residential well W-30.

- Excavate the contaminated soils in the "hot spot" areas and treat on-site with vapor extraction.

- Intercept and capture the contaminated groundwater via a series of wells and trenches; treat with contaminated groundwater utilizing an air stripper.

- Certain additional delineation of groundwater contamination and of soil quality beneath the General Switch building is recommended.

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Laurwal Holding Corporation

Transmitted on Behalf of Laurwal Holding Corporation

Jerome I. Gellman
Secretary

SECTION 1

CONTENTS

1.0 INTRODUCTION

This Site Characterization Report (Report) was prepared by Shakti Consultants, Inc. (Shakti), with assistance from Jacobs Environmental, Inc., pursuant to the Consent Decree entered on December 23, 1989 between General Switch Corporation (General Switch) and the United States Environmental Protection Agency (USEPA). This Report presents the findings of the site investigation activities that were conducted in accordance with the Revised Sampling, Analysis and Monitoring Plan (RSAMP) dated April 22, 1992.

1.1 ORGANIZATION OF THE REPORT

This Report is submitted in five volumes as follows:

- Volume I - Sections 1 through 9 of the Report
- Volume II - Figures and Tables
- Appendix I - Appendices 1 through 4
- Appendix II - Appendices 5 through 7
- Appendix III - Data Validation

A cross-reference list of well numbers and designations is included as Table 1-1 in Volume II, Figures and Tables.

Section 1.0 provides the organization of the Report, and presents the site description and the site background and history.

Section 2.0 provides the scope of the investigation, a summary of how each investigative activity was conducted, and the alterations or deviations from the RSAMP.

Section 3.0 describes the physical characteristics of the site area such as the geology and groundwater. In addition, that section presents the data obtained from a review of land use maps, soil survey maps and aerial photographs.

Section 4.0 presents the site hydrogeology determined from the evaluation of the slug and pump tests conducted at the site.

Section 5.0 describes the nature and extent of contamination of the soils, groundwater, sewers, surface water and wetlands.

Section 6.0 describes the pilot studies conducted at the site which consisted of a vapor extraction survey and the operation of a product recovery pump and an air stripper.

Section 7.0 presents an overview of potential fate and transport mechanisms with regard to the behavior of contaminants in the subsurface.

Section 8.0 sets forth a summary of findings, conclusions and recommendations for groundwater and soil contamination.

Section 9.0 provides a discussion of the possible and appropriate remedial actions for addressing the contamination detected at the site.

1.2 SITE DESCRIPTION AND LOCATION

General Switch is located in a residential community off Route 17M on the border between the City of Middletown and the Township of Wallkill in Orange County, New York. The General Switch site is adjacent to Highland Avenue and Industrial Place in Wallkill, New York, in an area called the Highland Avenue Extension (Figure 1-1, Site Location Map). This community, also known as the Annex of Washington Heights, is a residential community of one-family homes that includes the streets of Highland Avenue, Watkins Avenue and Commonwealth Avenue. Most of the houses in the community are over 30 years old and are one- or two-story homes on ¼-acre plots, as shown on Figure 1-2, Map of Study Area. An industrial subdivision on Industrial Place is part of the community. That subdivision includes the General Switch facility, Lubricants Inc., Guild Molders, a United States Army storage depot and the headquarters office of Wallace Oil. A grid map of the site is presented in figure 1-3. A base map is presented in Appendix 1.

The General Switch property is approximately 5 acres in size. General Switch's building, which was used until 1992 for the manufacturing of electrical switches, circuit breakers and panel boards, is a one-story cinderblock warehouse and office building of approximately 360 feet by 110 feet (40,000 square feet). The building is serviced by three loading docks on the south side that open up onto a one-acre parking lot.

The property slopes from Highland Avenue to the northwest to Industrial Place to the southeast. The southern half of the property adjacent to Industrial Place is a heavily wooded wetlands. In order to construct the building and parking lot, fill was imported to provide a level surface. The plant sits on the imported fill superimposed on the general slope of the land. Consequently, there is a 5- to 15-foot elevation difference between the top and bottom banks of the parking lot and the toe of the slope. The topography slopes to its lowest elevation near the southern edge of the General Switch property and Parella property adjacent to the north side of Industrial Avenue and then rises again in the area of Lubricants, Inc., where there is a bedrock outcrop.

Highland Avenue and Watkins Avenue are residential streets that run across the slope of the 100-foot-high hill that comprises the Annex. Commonwealth Avenue and Rockwell Avenue run parallel to Highland and Watkins Avenues along the crest of the hill. Industrial Place leads down from Highland Avenue to run along the valley bottom that used to be a railroad marshalling and repair facility and coal depot. An electrical substation, belonging to The Orange and Rockland Utility Company, is situated halfway down Industrial Place. Industrial Place is presently an industrial park and is the home of Lubricants, Inc., Guild Molders and Wallace Oil along with a storage yard for armored vehicles of the National Guard.

A new housing development was built in 1991-1992 across Industrial Avenue from General Switch.

1.3 SITE OVERVIEW

On October 17, 1983, the Parella well (320 Highland Avenue) was identified by the New York State Department of Health (NYSDOH) as being contaminated with tetrachloroethylene. Subsequent investigations by the USEPA and New York Department of Environmental Conservation (NYSDEC) identified the Stout, Ruppert, Barry, Liska and General Switch supply wells as being contaminated with over 50 ug/l (ppb) of tetrachloroethylene, which at that time was the Maximum Concentration Level (MCL) allowable in drinking water. The initial concentration of tetrachloroethylene in the Parella well (W-30) was 12,000 ug/l (ppb) or 12 mg/l (ppm), over 2,000 times higher than the acceptable level of tetrachloroethylene in drinking water according to the Safe Drinking Water Act. The MCL for tetrachloroethylene is Sugle (ppb), according to the April 1992 USEPA Drinking Water Reclamation and Health Advisories.

The data gathered to complete this Report confirms the presence of a plume of groundwater contaminated by tetrachloroethylene (perchloroethylene or PCE), along with lesser concentrations of other volatile organics including dichloroethylene (DCE) and trichloroethane (TCA), in the groundwater in the glacial sediments under the General Switch property and wetlands below the site, and in the shale and sandstone aquifer under Highland Avenue in the vicinity of the Parella, Stout, Ruppert, Barry and Contel residential bedrock wells.

Separate-phase PCE solvent has been detected in the Parella residential bedrock well which is approximately 200 feet west of the eastern corner of the General Switch building (Base Map, Appendix 1). A product recovery pump was installed in the well to remove free product from the bedrock aquifer by pumping the solvent to a storage container at the surface.

During initial site investigations conducted by Fred C. Hart Associates, soil contaminated principally with tetrachloroethylene was detected at three locations, designated areas TP-A, TP-D and TP-6, around the General Switch manufacturing building. These areas of soil contamination are potential sources of the groundwater contamination.

The original residences in the community were vacation cottages. The first cottages had dug wells to supply water. At that time, groundwater was generally found less than 20 feet below the ground surface in the glacial till. These homes were subsequently used year-round, and other residential houses were built along Watkins and Commonwealth Avenues. Deeper domestic wells were drilled to depths of 100 feet to 200 feet into the shale bedrock to supply these homes with more reliable water sources. While many of the residences along Watkins Avenue were supplied with public water by 1983, the majority of the residences along Highland Avenue continued to be supplied by their individual wells.

The Austin Glen Series sandstone and shale is the primary aquifer tapped by the residential wells and is found beneath 25 to 100 feet of glacial till under the General Switch site. Aquifer testing, discussed in Section 4 of this Report, indicated this is a semi-confined bedrock aquifer in that the bedrock is covered with dense glacial till and the groundwater in the shale is under such pressure as to rise up in wells tapping the shale to a level above the top of the shale. However, leakage into the bedrock occurs from the glacial till overburden. The groundwater in the confined shale aquifer may be restricted to regional or local fractures and bedding planes that have a major influence on the availability and flow of groundwater in the semi-confined aquifer.

The direction of groundwater flow in the bedrock aquifer in 1992 was due south from Highland Avenue and from General Switch. However, prior to 1984 when the residential wells were active, contaminants located in the shale near General Switch tended to move westward toward the Parella well and subsequent downgradient residential wells, probably due to the pumping of these wells.

1.4 SITE HISTORY

The General Switch plant was built in 1958 and both the original parking lot and building were about half their present size as indicated on the aerial photographs (see Section 2). At that time, the area adjacent to the parking lot was used for disposing of scrap metal and industrial waste generated by the plant. In 1963, the plant was enlarged to its present size and fill that contained old scrap metal was used when the parking lot was expanded.

Tetrachloroethylene was used as a degreaser to clean the electrical parts in the manufacturing process. The metal parts used in the switch boxes and circuit breakers were carried on a conveyor belt and dipped into a tank containing tetrachloroethylene to clean all the accumulated oil and grease. Tetrachloroethylene was originally stored inside the plant in a 500-gallon above ground storage tank and the chemical was delivered by tank truck to the rear loading dock, where it was piped into the storage tank. The tetrachloroethylene was drained from the tank and the 500-gallon tank was sold for scrap metal. Since 1987, the tetrachloroethylene was delivered to and stored inside the plant in 55-gallon drums. The spent tetrachloroethylene went through an on-site distillation process which produced an end waste product consisting of a 50 percent tetrachloroethylene-oil mixture. The still bottoms were then sent to another facility to be reprocessed.

From October 17, 1983, to March 16, 1984, water samples from potable wells within a one-mile radius of the General Switch plant were analyzed for tetrachloroethylene. The data generated from over 300 groundwater samples indicated that 20 wells on Highland and Watkins Avenues had detectable concentrations of tetrachloroethylene. Seven domestic wells and one industrial well (at General Switch) contained concentrations of tetrachloroethylene that exceeded the NYSDOH maximum permissible concentration of 50 ppb for any single synthetic organic chemical. These seven domestic wells are the Robaina, Barry, Ruppert, Stout, Lobb, Osbourne, and Parella wells. The contamination appeared to be distributed in a northeast-southwest line, with the most contaminated well (260,000 ppb) on the Parella property adjacent to General Switch on the northeast side. Lower concentrations of tetrachloroethylene (less than 50 ppb) were found in some wells along Highland Avenue and Watkins Avenue, and wells on Commonwealth Avenue appeared to be totally unaffected. The results also showed that the distribution of tetrachloroethylene in the groundwater changed little over the 3-month period of the 1983-1984 investigation.

In October 1983, in response to analytical results of samples from contaminated residential wells from contaminated in the Annex community of Wallkill, the Orange County Health Department declared an Area of Concern at the site to encompass the wells on Highland Avenue, Watkins Avenue, Commonwealth Avenue and the cross streets Electric and Park Avenues.

To address the public health emergency of the immediate threats of the plume of contaminated groundwater to the residents of the Annex, on November 16, 1983, USEPA initiated a Removal Action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) pursuant to Section 101(25), 42 U.S.C. 9601(25) and arranged that General Switch provide bottled water to the residents with supply wells contaminated with tetrachloroethylene at concentrations over 5 ppb.

In order to extract tetrachloroethylene from the bedrock aquifer, under that Removal Action, the Technical Assistance Team (TAT) contractor to the USEPA and the USEPA's Emergency Response Team pumped the Parella well from October 17, 1983, to December 26, 1983, to intercept the plume at the Parella well.

The Parella well, used as the extraction well, was pumped at a rate of 0.5 to 4.0 gpm and an estimated 21 pounds of tetrachloroethylene was removed. In the process of pumping the Parella well, it was noted that the radius of influence of the drawdown in adjacent wells was anisotropic in plan view and limited to a 350-foot radius from the Parella well. During this period water samples were taken from the wells throughout the Area of Concern.

In November 1983, a temporary water line was constructed above ground and insulated with heat tape and hay bales to supply affected residents on Highland Avenue.

In response to an Administrative Order issued by the USEPA on May 1, 1984, General Switch provided an underground water main down Highland Avenue that tapped the water main on Industrial Avenue leading from the Wallkill municipal water supply. The system was designed under contract to the Town of Wallkill by Eustance and Horowitz of Fishkill, New York, who also completed the mapping of topography and well locations and elevations. In 1986 the water supply to the Annex was completed with a new trunk main to Highland Avenue.

In December 1983, the NYSDEC sampled soil from depths of 0 to 2.5 feet at a location just south of the plant building. The results of the chemical analyses showed relatively low concentrations of tetrachloroethylene at the top and bottom of the hole and higher concentrations (100 ppm) at depths of one to two feet. A second round of soil samples was taken from within a 100-foot radius of the plant in March 1984. The most contaminated sample (1,000 ppm tetrachloroethylene) was found on the northwest side of the plant. Two samples from the southwestern corner of the plant contained 95 and 400 ppm tetrachloroethylene, while the other soil samples contained only 10 ppm.

Subsequently, in 1984-1986, Fred C. Hart and NYSDEC identified tetrachloroethylene-contaminated soils at three locations designated "hot spots" on the General Switch property, a distance of 200 feet from the Parella well, Figure 1-4. A site investigation of the glacial till under the General Switch property was completed by Fred C. Hart in November 1984. The study included a soil vapor survey, geophysical testing to locate metal (including any drums in the fill on the General Switch property), eight monitoring wells (MW-1 to MW-8) and residential well sampling and was reported in the document entitled "Hydrogeologic Investigation of the General Switch Site," (Fred C. Hart, November 1984). A second report entitled "Soils Investigation to Determine the Extent of Tetrachloroethylene (Tetrachloroethylene) Contamination at the General Switch Site" was presented on April 10, 1986, and further identified three hot spots of soil contamination on the General Switch property. These reports were included in the Appendix of the RSAMP.

1.5 SURROUNDING INDUSTRIES INFORMATION SEARCH

The following information about the surrounding industries was obtained through requests under the Freedom of Information Act and reviews of commercially available database searches.

Additional information regarding potential sources of contamination in the surrounding area was obtained by filing a Freedom of Information request with NYSDEC. The facilities reviewed include Lubricants Inc. and Guild Molders located on Industrial Avenue Extension, Cosmo Optics located on Watkins Avenue, the dry cleaner located at the junction of Highland Avenue and Route 17, and others. The facilities targeted for review were believed to have used solvents.

Freedom of Information requests to New York State and USEPA were sent out in the week of May 25, 1992, regarding Lubricants Inc., SOS Fuel Co., Guild Molders, Contel, Wallace Oil, Cosmo Optics and the dry cleaners and fabricating shops along Watkins Avenue. A positive reply that data existed on several industries was received from NYSDEC on November 10, 1992, and an appointment was made to view the files of the NYSDEC on January 15, 1992. The file search conducted at the NYSDEC office in Albany revealed that there is little information available on the aforementioned facilities.

A package of information was received from NYSDEC, USEPA and VISTA Data Inc. The following summarizes the information that was obtained:

Lubricant Packing Supply Co. is located at 17 Industrial Place, 0.17 mile southwest of the site. Lubricant Packaging and Supply Co. is classified as a RCRA Large Quantity Generator, which generates at least 1,000 kilograms per month of non-acutely hazardous waste (or 1 kilogram per month of acutely hazardous waste). The site was used as a facility for the degreasing and relubrication of bearings. The operations involved the use of listed hazardous wastes, namely tetrachloroethane, 1-1-1-trichloromethane and mineral spirits, for degreasing. Waste oil was also handled at the site.

On February 7, 1983, the manhole of the Middletown sewer running down Industrial Place was sampled adjacent to Lubricants, Inc., and 2,400 ppb tetrachloroethylene was detected. On December 8, 1983, trace tetrachloroethylene was detected in the soils at 4.5 ppb in the north-rear yard at Lubricants, Inc., in the vicinity of the drum storage area.

During inspections conducted by the NYSDEC compliance inspection staff in February, March, and August 1987, several hundred drums of hazardous waste and some storage tanks of listed hazardous wastes were identified as being stored on site without proper TSD permits. Many of the drums were leaking and soil contamination was extensive. The results of samples taken from 25 drums confirmed the presence of the hazardous wastes described above. The drums were removed from the site in March 1991.

Extensive on-site soil contamination has been caused by improper storage and handling of solvents and waste oil. The site is located in an industrial area. Lubricant Packaging no longer resides at this location; however, a different company now leases the building. The facility is supplied by public water. The building is fenced in with exception of the front of the building. A proposed Phase II investigation at that site will provide information as to whether hazardous wastes at the site constitute a significant threat to the public health or the environment.

Due to the lack of information regarding the extent of contamination on-site and off-site at the Lubricants Inc., facility, its impact on the General Switch site and surrounding area cannot presently be evaluated.

Cosmos Optics, Inc. is located at 238 Watkins Avenue about 0.16 mile northwest of the site. Cosmos Optics generates between 100 and 1,000 kilograms per month of non-acutely hazardous waste and is classified as a RCRA Small Quantity Generator.

Guild Molders, Inc., is located at 17 Industrial Place. Guild Molders generates between 100 and 1,000 kilograms per month of non-acutely hazardous waste and is classified as a RCRA Small Quantity Generator.

SECTION 2

CONTENTS

2.0 SITE INVESTIGATIONS

2.1 BACKGROUND INFORMATION

This section describes the investigative activities completed between May 8, 1992, and June 1993, in the study area known as General Switch. The site investigation included a subsurface geophysical investigation, soil borings and soil sampling, monitoring well installation, residential well and groundwater monitoring well sampling, and surface water and sewer sampling. In addition, assessments were made regarding the operation of the air stripper during cleanup and the feasibility of in-situ vapor extraction for contaminated soils. A detailed explanation of the pilot studies is discussed in Section 6.0, Pilot Studies.

This site investigation was performed to provide information on the extent of the groundwater and soil contamination in the vicinity of the General Switch property.

A second goal of this investigation is to provide sufficient data on which to base the chace of appropriate cleanup methods and subsequently to direct and monitor the proposed cleanup methods to determine that the methods are successful. In this regard, under the Sampling Plan, a pump test of well W-30 (Parella) was completed that determined that well W-30 (Parella) alone would be insufficient to capture the plume of contaminated groundwater. Section 4 summarizes the hydrogeologic investigations.

2.1.1 Deviations from the RSAMP

All investigative activities conducted outside the limits of the General Switch property were subject to obtaining approval for site access from each property owners. In general, the residents of the community were cooperative regarding this fieldwork including access to their property for soil borings, monitoring well installation, sampling and pump tests. The exceptions to the RAMP that relate to site access and their resolutions are discussed below.

The property owner at 334 Highland Avenue refused access to his property of approximately 1/4 acre adjacent to the northern property line of General Switch. That property was to be included in the surface geophysics survey. Initially, the property owner gave permission for the geophysics survey but subsequently removed the survey stakes. His property was not entered during any subsequent work.

The property owner at 304 Highland Avenue granted access for the geophysics survey but not for drilling MW-14, which was to be cored 10 feet into bedrock. As the deep well at 304 Highland Avenue had been filled with stone/soil and abandoned, USEPA agreed that the proposed shallow well MW-14 could be installed on the adjacent property, next to well W-33 (Contel), and to provide for monitoring a nested deep well (Contel) and shallow well (MW-14) during the short-term Ruppert/Barry pump testing. The 10 feet of rock coring scheduled for MW-14 was completed on the Contel property. The location of the well nest on the Contel property is 150 feet from the proposed location on the Liska property. The Contel deep bedrock well is a prolific well that influences much of the hydrology of the sites. The placement of the well nest at the Contel site improved the quality of data in the RSAMP.

The Sleiter (now Petruzzio) soil boring was to be located at 296 Highland Avenue in the middle of the resident's garden and permission was withheld. With USEPA permission, the Sleiter soil boring was installed across Highland Avenue in the open lot south of the Hebrew School, at 305 Highland Avenue, west of the Ruppert property.

Access for the well Ruppert MW-15, which was to be cored 10 feet into bedrock, was refused because the house was being sold. This well was subsequently located on the adjacent Barry property (309 Highland Avenue). In addition, other field activities that were to be performed on the Ruppert property (307 Highland Avenue), such as geophysical logging, were also moved to the Barry property (309 Highland Avenue). The Barry deep well was found to be hydrologically linked to the Contel well. The focus of field activities on the Barry well allowed the assessment of hydrologic and structural characteristics of the Barry well that has proved to be an important candidate for a groundwater recovery well.

Rock coring and step test at MW-204 in the wetland were not performed in order to avoid additional pathway for contaminant migration from upper strata to deeper bedrock. A letter to this effect dated January 19, 1993, was submitted to USEPA.

The soils at General Switch were too dense and stony to obtain undisturbed samples, such as those obtained with Shelby tubes. Thus, physical testing of soils that need an undisturbed sample was not completed.

During the sewer sampling, three manholes could not be located under the freshly paved road surface and were not sampled.

Continuous soil sampling was required per the RSAMP. During soil borings to bedrock at MW-22 (Hebrew School) a modified soil sampling procedure was adopted. Soil samples were taken every 5 feet down to 20 feet and then every 10 feet to bedrock. USEPA's prior concurrence was obtained for this in a memo dated September 1, 1992.

The shallow rock well at 316 Highland Avenue was to be drilled 10 feet into the bedrock. Due to absence of water at 10 feet into the rock, this well was drilled 30 feet into the rock. USEPA was informed about the issue in the subsequent monthly progress report.

The step test of various wells were to be conducted to select the best responsive wells to be monitored during the 3-day pump test of W-30. However, the step test on MW-203 was performed after the 3-day pump test. The step test on MW-204 in the wetland was not performed at all in order to avoid downward migration of contaminants into the bedrock. USEPA was informed about this in a memo dated January 19, 1993.

MW-9 and MW-204 in the wetland were not samples during the first round of groundwater sampling permission by USEPA and the U.S. Army Corps of Engineers was not granted to install MW-9 and MW-204 in the wetland until after the end of the first round of groundwater sampling. USEPA was notified of this in the subsequent monthly progress report. MW-204 was sampled during the second round of groundwater sampling. However, MW-9 was not installed at that time and was sampled on May 28, 1993.

The second round of groundwater was sampled 3 weeks after the end of the first round of samples in order to comply with the intent of the 3-day pump test and assess the affect of the pumping upon the regional groundwater quality, and to complete the RSAMP in a timely fashion.

An extra soil boring, SB-24, was conducted between area TP-D and area TP-6.

Four water samples, WET-001 through WET-004, in the wetland could not be collected as there was no surface water present in the wetland during two sampling events. However, two wetland sediment samples, designated as WET-003 and WET-004, were collected. This was documented in subsequent monthly progress reports.

2.1.2 Mobilizations

Site work was begun on May 8, 1992. Access roads were constructed to allow the drill rig access to the proposed well drilling sites. Survey crews from Eustance and Horowitz began the layout of the baseline and grid points for the geophysical survey that was to follow.

2.1.3 Waste Storage and Decon Pad

The waste storage and decon pad was constructed on May 9-10, 1992. The decon pad was constructed of a series of heavy-duty plastic liners and sheeting on which was placed plywood sheets for vehicle access. The decon pad was used to clean the drill rigs and ancillary equipment between each soil boring and monitoring well installation. Decontamination of sampling equipment was also performed on this pad. Waste water from the decontamination procedures was pumped from a sump/depression constructed in the decon pad into a 7,000-gallon-capacity tanker for storage prior to treatment by the on-site air stripper.

2.1.4 Site Management (Exclusion Zones/Hot Zones)

Figure 2-1 shows the Site Management Areas.

2.1.5 Designated Work Zones

Work zones were established prior to initial site entry in order to reduce the exposure of the site workers and visitors to the contaminants and limit the spread of the contaminants. A perimeter fence was installed in the rear parking area and loading dock area of the General Switch plant. This served to restrict access to the work area to authorized personnel and demarcate the work zone from the clean zone. An office trailer was transported to the site to serve as a command post for the field activities. Computer and laboratory facilities were established in this trailer, along with storage space for field equipment. An access control point was established at the trailer to restrict entry and exit. All site visitors first the ongoing work.

Work zones were adjusted to reflect the potential exposure.

The three areas of soil contamination (TP-A, TP-D and TP-6) and well W-30 (Parella), known to contain hazardous substances, were designated the Exclusion Zone. Activities at these sites during soil disturbance and the pumping of contaminated groundwater were monitored with organic vapor analyzers according to the site Health and Safety Plan. Work zones such as around well W-30 (Parella) were divided into sub-areas based upon varying levels of hazard and/or the nature of the tasks to be performed. All personnel within the Exclusion Zone wore the required level of protection based on the site-specific monitoring of the air.

The Contamination Reduction Zone was the buffer area in the vicinity of the air stripper delineated with wire fencing. This area provided a transition between contaminated and clean zones. This zone contained the decontamination activities and was separated from any Exclusion Zone by the Hot Line and from the Support Zone by the Contamination Control Line.

The Support Zone was the rest of the site and was considered to be clean or uncontaminated except around any contaminated well during groundwater pumping. The Support Zone contained the command post and site support facilities. It was positioned upwind of the Exclusion Zone and was in the southern parking lot of the site.

2.1.6 Site Entry and Exit and Security

For site personnel all site entry and exit to the General Switch site was through the eastern site gate. Special site visitors were required to register at the office trailer and await a site guide.

For on-site activities of known or potentially high hazard, emergency escape routes were delineated due north to Highland Avenue and due east through the eastern gate. The rendezvous point was on the lawn outside the front door of the General Switch building.

All personnel connected with a site and engaging in field activities were briefed on standard operating safety procedures and any additional instructions contained in the Site Health and Safety Plan before site entry.

Further, all personnel, upon their initial visit to the site, were instructed in the Health and Safety Plan before performing any site-related activities.

Personnel were briefed on anticipated hazards, designated level(s) of protection, special equipment to be used, safety practices to be followed, emergency procedures and site communications prior to going on-site.

A copy of the Site Health and Safety Plan, which addressed safe work practices and the availability of emergency medical care and treatment of response personnel, was kept in the trailer. All individuals involved with the site read the Health and Safety Plan.

2.2 MAPPING AND GEOPHYSICAL SURVEY

2.2.1 Base Map and Topographic Map

The topographic base map prepared during the 1985-1986 Fred C. Hart site investigation was upgraded by additional site surveying and by comparison to recent aerial photographs taken during selected annual low-altitude flights over the subject area. Five base lines were surveyed on the General Switch property. Three base lines were surveyed parallel and two lines perpendicular to Highland Avenue. The baseline node locations were measured on 40-foot centers and tied to a surveyed benchmark that was a USGS datum. The topographic base map scale was one inch equals 100 feet with two-foot contour intervals.

Utilizing these five base lines, a grid with 40-foot centers was surveyed encompassing the General Switch, Parella (320 Highland Avenue), Stout (316 Highland Avenue), Liska, Ruppert (307 Highland Avenue) and Perez (338 Highland Avenue) properties in order to provide a reference for the geophysical survey.

The topographic map was developed utilizing CAD (Computer Aided Drafting) and is included in this Report as Map 2-1 in Appendix 2. This base map was used by Delta Geophysics to tie in the surface geophysics mapping. This topographic map at 2-foot contour intervals containing the surface geophysics data was provided to the USEPA and is included as Map 3-1 in Appendix 3-1.

Aerial photographs of the site were obtained and used to locate the surface expression of pronounced fractures and anomalies in the bedrock (see Section 2.2.2).

Utilities and services were staked out during the week of May 25, 1992, by the appropriate agencies. Water, natural gas, electric, telephone and sewer services were color coded by the utility on the pavement throughout Highland Avenue, Wallkill Avenue and Industrial Place. These services were located and plotted on the base map by the surveyor. No utility services were damaged during the site investigation.

2.2.2 Fracture Trace and Structure Survey

A fracture trace survey was completed to determine areas within the bedrock where increased groundwater flow and potential contaminant migration occurred. The survey was completed initially by tracing the prominent fractures and features identified on the aerial photographs (both black and white and color stereo pairs) onto the topographic base map and verifying the features in the field. Copies of the photos may be found in Figures 2-2 to 2-6. Aerial photographs were obtained from Robinson Aerial Survey, USGS - ERIS High Altitude Program during the week of June 22, 1992. The aerial photographs were reviewed by Delta Geophysics, to determine the correlation between aerial photo traces and surface geophysical anomalies. The map correlating this geophysical and aerial photo information may be found in Appendix 2.

2.2.3 Geophysical Surveys

2.2.3.1 Previous Geophysical Investigation by Fred C. Hart

During the previous site investigation by Fred C. Hart, a Geometric G-846 Unimag II Proton Precession magnetometer was used to investigate the fill in the General Switch parking lot. The magnetometer was used to detect the presence of ferromagnetic material such as iron or steel.

A Fisher Model TW-5 M-Scope metal detector was used to detect metal but was limited to an effective depth of penetration of only 4 feet in the upper soil horizons.

An extensive survey was conducted with the metal detector in the General Switch parking lot. Instead of using the reference grid the metal detector was left on and carried by hand in traverses that completely covered the parking lot.

The areas surrounding the parking lot were covered by traverses along the 25-foot-interval grid lines. Particular attention was paid to areas where the magnetometer had shown anomalies, where surface metal was found or where the topography appeared unusually disturbed. The results of the survey are reported in Section 3.

2.2.3.2 Geophysical Survey Conducted by Delta Geophysics

A surface geophysical survey was performed between June 10, 1992, and June 13, 1992, to investigate the subsurface geological structure at the General Switch site, and in particular, any fracture locations and patterns to locate regional fractures, which may be capable of carrying dense non-aqueous phase liquid (DNAPL) and the dissolved plume. This survey was also used to determine the best location for monitoring wells and recovery wells.

On the first morning of the survey, VLF ABEM Wadi conductivity equipment was used that detects the disturbance caused by geological structures and water bearing zones. This equipment utilizes very low frequency radio waves broadcast as part of a global navigation network for its detection capability. Data was gathered at 20-foot intervals along transects 480', 560' and 640' as laid out on the baseline grid map (Geophysics Base Map, Appendix 2). These transects run in a northwesterly-southeasterly direction, and were located so as to intersect the major linear features interpreted from the aerial photos.

The VLF equipment that was used on the first day did not detect the linear anomalies noted in the aerial photographs. Although numerous factors may have prevented the detection of these fractures, the major reason may be due to the sedimentary origin of the rock (shale and sandstone). The VLF method is optimum in crystalline rock such as granite and gneiss, although it has been used with success in the Brunswick Shale. As the VLF method was not useful for locating the major water-bearing geologic structures and for selecting the optimum locations for monitoring and recovery wells, it was discontinued after the first morning of field work.

An EM-34 was subsequently employed that utilizes electromagnetic waves and frequencies as its method of detection in the area denoted in Figure 2-7, Site Map with VLF Survey Data.

This equipment and method was more effective and recorded a series of northeasterly-southwesterly (NE-SW) linear anomalies around General Switch that may be rock fractures, linear trends in the rock surface such as troughs or linear trends in the overburden. These linear trends are displayed on the Geophysical Base Map in Appendix 2.

2.2.4 Borehole Geophysical Logging

Borehole geophysical logging was conducted in order to obtain additional information on the frequency and location of fractures in the existing water supply wells and in the shallow and deep groundwater monitoring wells. The wells were logged for natural gamma, conductivity/resistivity and three-point caliper measurements.

The following fourteen borings, monitoring wells and residential wells were logged:

- The shallow rock borings designated as SB-1, SB-5 and SB-11
- The deep rock wells MW-202, MW-203, MW-204 and MW-207
- Wells W-30 (Parella), W-8 (Osbourne), W-31 (Electra Manufacturing), W-32 (Stout), W-33 (Contel), and W-17 (Barry) residential wells

Well W-18 (Ruppert) was originally to have been logged; however, due to the denial of site access, the activities were switched to the Barry property (309 Highland Avenue). In addition, MW-12, located on the Parella property, was cored and logged throughout its 25-foot depth. These borings and wells are shown on Figure 2-8, Site Map with Geophysical Logging Locations.

The geological core data were used to develop a correlation between the geophysical log signatures and the rock coring log with its observed lithologies, bed thicknesses, depths of formations and fractures. These logs were used to define the site-wide stratigraphy. In addition, the log signatures of newly cored wells were compared to those of the older residential wells. For example, well W-30 (Parella) was compared to monitoring well MW-12, cored 25 feet into the top of bedrock on the Parella property. The findings are presented in Section 3.

2.2.4.1 Caliper Logging

The frequency and locations of potential fractures in the heavily contaminated wells were determined by caliper logging, whereby the instrument was lowered down the wells and then raised to take measurements along the borehole walls. Roughness and indentation of the borehole wall may indicate potential fracture zones or other areas of preferred groundwater flow that were designated for sampling. This sampling would determine if that particular fracture was carrying the contaminant plume. In the residential wells, the depth to the bottom of the casing was also indicated in the caliper log.

2.2.4.2 Conductivity/Resistivity Logging

The conductivity/resistivity probe used in the down-hole geophysics logging measured the ability of the borehole fluid and formation matrix to conduct electrical current. The conductivity of well water is changed by dissolved or free phase solvents entering the well bore. Those areas that indicated a fracture zone during the caliper logging were studied to determine if a significant variation in conductivity occurred.

A typical well log is presented in Figure 2-9, and the full complement of logs is presented in Appendix 2.

As the conductivity/resistivity changes with alternative shale and sandstone lithology down the profile of the wells, the study was not able to distinguish conductivity changes caused by contaminants in the groundwater. However, the study was able to distinguish lithology changes and corresponding resistivity anomalies at the interface of the changes between sandstone and shale that may indicate that water is traveling along the change in lithology or in the coarser sandstone immediately above that juncture.

2.2.4.3 Bladder Pump Sampling

In order to obtain information on the presence of fractures and any DNAPL carried through fractures, a bladder pump was used to obtain samples at 20-foot intervals down the profile of the following seven wells: W-30 (Parella), W-32 (Stout), W-33 (Contel), W-17 (Barry), W-18 (Ruppert), W-8 (Osbourne) and W-1 (Perez). A discrete sample was obtained from each interval and analyzed in the field utilizing the Photovac gas chromatograph. At least 10% of the samples (approximately six) were submitted for laboratory analysis by USEPA Method 624.

Between the weeks of June 8, 1992, and July 3, 1992, prior to the Phase I pump test, the Marschalk bladder pump was used in wells W-30 (Parella), W-8 (Osbourne), W-18 (Ruppert), W-32 (Stout) and W-17 (Barry) to sample fractures capable of carrying contaminants. No free product was noted in the base of any of these wells. Duplicate samples from zones of high groundwater contamination and from the base of the residential wells were analyzed for volatile organics by Method 624/524.2 in the CLP laboratory.

Bladder sampling of MW-202, MW-203, MW-207 the Electra Mfg. and W-33 (Contel) wells was completed.

In order to identify any fractures in well W-1 (Perez) upgradient from General Switch, bladder sampling of well W-1 (Perez) was completed in the week of January 25, 1993.

2.2.4.4 Packer Tests

The results of the caliper logging, the conductivity logging and the bladder pump sampling were compared and correlated to determine the presence of fractures down the profile of the wells and the possible presence of fractures carrying DNAPL or dissolved solvent.
The arrangement of the packer equipment in the well is detailed in Figure 2-10. Once these fractures and anomalies were located, the wells were packed to isolate the fractures. The packer testing is detailed in Section 4.0 of this report.

2.3 WALLKILL WATER SUPPLY SURVEY

The Wallkill Well Data Survey conducted in 1983-1984 by the Technical Assistance Team contractor to USEPA included the wells on Industrial Place, Highland Avenue Extension, Electric Avenue, Watkins Avenue and Commonwealth Avenue (the study area). This survey was updated to reflect current conditions. Field work for the Well and Water Supply Survey began the week of May 31, 1992, and was completed by June 29, 1992. The updated tables are included in Appendix 3.

Information was collected from residents and the Township of Wallkill and the City of Middletown to determine the present source of the water supply for residences in the study area. The information from the municipalities was augmented by a door-to-door survey of all of the wells in the study area. In addition, information regarding the condition of the wells in regard to ease of access to the well for sampling, water level measurements and the status of the well pump was collected. Figure 2-11, Residential Water Supply, indicates the information that is currently available.

2.4 SURROUNDING INDUSTRY INFORMATION SEARCH

Additional information regarding the stratigraphy of the area and extent of contamination was obtained in from studies conducted at other facilities in the surrounding area by filing A Freedom of

Information request with the New York State Department of Environmental conservation (NYSDEC). These facilities include Lubricants Inc. and Guild Molders located on Industrial Avenue Extension, Cosmo Optics located on Watkins Avenue, the dry cleaner located at the junction of Highland Avenue and Route 17, and others. All of these facilities were believed to have used solvents and the findings were discussed in Section 1.5 of this Report.

2.5 SOILS INVESTIGATION

The soils investigation focused on obtaining additional information on the physical/geologic characteristics of the site and on defining the extent of soil contamination.

2.5.1 Soil Borings and Sampling

A total of 25 borings were drilled at the site during this study, as indicated on Figure 2-12, Site Map with Permeability Test Pit Soil Boring Locations, and as described below. All drilling activities were performed by a registered professional driller using a hollow-stem auger drill suited to this formation. Careful observation of the soil quality and type allowed a determination to be made of the ability of contaminants to migrate through the soil. A mud rotary drilling method was used in the Stout boring when extremely dense till and boulders were encountered.

Fifteen soil borings, designated as SB-1 through SB-14 and SB-24, were drilled adjacent to and through the areas of soil contamination (hot spots) at the General Switch property. These borings were drilled to the top of bedrock to define the extent of contamination under and adjacent to the three areas of soil contamination in the glacial till. Soil samples were collected in the hot spots from each boring every two feet down the profile of the boring until the top of bedrock was encountered.

Samples were collected utilizing a 2-foot split spoon sampler (ASTM method 1586) made of carbon steel. All split-spoon samples were immediately placed in 40 ml vials. The samples were analyzed using a Photovac 10S50 and the relative concentrations of soil contamination were determined before two samples in each soil boring were selected for laboratory analysis.

Each soil sample was removed immediately upon recovery of the sampler and carefully described and logged. This description was completed in accordance with the Unified Soil Classification System and included the sample number, date, depths, soil types and water locations. A boring log was prepared by the on-site geologist. The boring logs were presented in Appendix 7.

Each soil sample was collected for laboratory analysis as well as on-site analysis in 40-ml septum vials. The sample containers were supplied by the laboratory and cleaned according to USEPA protocol. Only the bottom two-thirds of the sample vial were filled for the on-site analysis. The sample vials destined for laboratory analysis were filled to the top with no headspace.

Soil borings SB-1 through SB-4 were drilled to bedrock around TP-6, and SB-14 (MW-16) was drilled to bedrock through the center of TP-6 at the base of the change of slope of the fill at General Switch. Soil borings SB-5, SB-6 and SB-7 were drilled to the top of bedrock to define the western, southern and northern limits of TP-A adjacent to the back door, and SB-13 (MW-17) was drilled to bedrock in the center of the TP-A hot spot. Soil borings SB-8 through SB-11 were drilled to bedrock to define the limits of TP-D adjacent to the southern loading dock, and SB-12 (converted to MW-18) was drilled to bedrock through the center of hot spot TP-D. An additional soil boring, SB-24, was drilled to define the extent of contamination to the southeast of TP-D.

In order to obtain information on the depth to bedrock to the far west of the study area on Highland Avenue and on Watkins Avenue, two soil borings, designated SB-22 and SB-23, were drilled. Boring SB-22 was drilled 95 feet to bedrock on the Hebrew School property on Highland Avenue and SB-23 was drilled 118 feet to bedrock on the Winner property on Watkins Avenue.

In order to determine the extent of soil contamination in the glacial till, the soil type and the depth to bedrock at the periphery of the site along Highland Avenue, four soil borings, designated SB-15/MW-12, SB-16/MW-15, SB-17/MW-13 and SB-18/MW-14, were drilled to bedrock. These borings, which were converted to monitoring wells, were adjacent to Parella (320 Highland Avenue), Stout (316 Highland Avenue), Contel (306-314 Highland Avenue) and Barry properties (309 Highland Avenue) (Figure 2-12).

To obtain additional information on the soil types and depth to bedrock south and east of well W-30 (Parella), three soil borings, designated SB-19/MW-10, SB-20/MW-9 and SB-21/MW-11, were drilled to the top of bedrock. These borings were converted to monitoring wells.

2.5.1.1 On-Site Volatile Organic Analysis

Volatile organic screening of selected split-spoon samples collected from the soil borings was used to determine the vertical distribution of contamination through the soil column. The soil samples were screened in the field for the presence of volatile organics with a Photovac gas chromatograph set up in a vehicle on site. The vial septum was pierced by a 100-ul syringe and the head space vapor concentration was determined by injection into the Photovac gas chromatograph. The on-board computer of the Photovac was calibrated against a 1 mg/kg standard of tetrachloroethylene in water supplied by the laboratory.

The analytical results of the Photovac and laboratory chemical analyses and their correlations are included in Section 5 of this Report.

The soil borings were sampled and analyzed on site for volatile organics using the Photovac 10S50 gas chromatograph. The results of this field screening were used to direct the subsequent field work and well installation.

2.5.1.2 Laboratory Analysis Samples

At the conclusion of each test boring, based on the results of the volatile organic screenings, a decision was made as to which samples were to be sent to the laboratory for chemical analysis. At least two samples per boring were selected to be submitted to the laboratory for TCL volatile organic analysis by Method SW846 and CLP protocol. In general, the soil samples that exhibited the highest and lowest concentrations by the on-site screening were selected for laboratory analysis.

Those samples not used for any chemical analyses were available for grain size determination and other analyses.

The latest version of the Hnu Photoionization detector (PID), with a data logger/industrial hygiene computation package, was used to monitor air quality at the soil boring operations. Air samples during drilling were obtained on Tenax tubes and sent to NYTEST for analysis.

2.5.2 Permeability Testing of the Glacial Till

One of the alternatives for soil treatment to be assessed was soil flushing: the infiltration of water into the residual contaminated soils in the hot spots to mobilize the contaminants into the groundwater for capture and treatment at a recovery well.

In order to determine the rate of water that the glacial till will allow to percolate through the soil profile into the aquifer, an infiltration permeability test was completed.

A test pit was excavated in clean soil remote from the hot spots defined on the General Switch property, indicated in Figure 2-13, Test Pit Location. The location was 20 feet southwest of MW-1, which is screened at the base of the glacial till, and 20 feet northwest of Electra Manufacturing (W-31) deep residential well. A metered volume of potable water was discharged into the excavation. The excavation was filled with water and the water was maintained at a consistent level. The response of the water levels in the shallow and deep monitoring wells to a known surcharge volume of water was measured with an electropiezometer system that recorded water levels in nearby wells, confirmed by hand measurements of the water levels over the ensuing 24 hours.

2.5.3 Physical Soil Testing

Samples of the glacial till were collected of representative soils present on the site in soil borings SB-1, SB-5, SB-11, SB-19, SB-20 and SB-21. The till was too dense and stony to obtain any Shelby tube samples. The Shelby tubes bent and buckled when they were driven into the soil. Thus, loose soil was tested for the following parameters to augment the visual classification of the soil to characterize the material according to the following engineering properties:

- Atterberg limits
- Particle size distribution
- Moisture content

As only loose soil was obtained because of the dense and stony nature of the till, bulk density and vertical hydraulic conductivity measurements could not be attempted as undisturbed samples are required for these measurements.

The results of the physical soil testing, including the results of the permeability analysis, are included in Section 3.

2.5.4 Rock Coring and Rock Wells

Rock cores were obtained in the bottom of selected soil borings to confirm the top of bedrock and obtain core samples of the top of bedrock.

Coring was performed in or around each hot spot and adjacent to selected residential wells to determine the degree of fracturing of the bedrock. The core was obtained through the bottom of SB-1, SB-5 and SB-11, as well as in MW-12 adjacent to well W-30 (Parella), and SB-16/MW-15 adjacent to well W-17 (Barry), as shown in Figure 2-14, Site Map With Rock Coring Locations. Access was not granted to drill MW-14 on the Liska property nor for the rock coring at MW-13 adjacent to SB-15/Stout well. However, SB-18 was drilled and cored to 10 feet on the Contel property mid-way between Stout and Liska.

The field chromatographic analysis of soil samples from the soil borings SB-1, SB-5 and SB-11 through the hot spots TP-D and TP-6 indicated there was contamination of the glacial till above the bedrock but no free product. Rock coring was completed, in all cases, inside a casing isolating the top of bedrock from the glacial till. Each soil boring and rock coring that was not completed into wells was grouted up with Portland cement.

The rock cores obtained were 2 inches (NX) in diameter, obtained in 10-foot lengths according to the standard operating procedures detailed in the RSAMP. A 25-foot-long rock core, from 32.5 to 57.5 depth, was obtained from SB-15/MW-12 (adjacent to W-30 the Parella well) in order to coordinate the information from well W-30 (Parella) and the adjacent areas. The 200-series wells except MW-204 were cored to a depth of 100 feet. Monitoring well MW-204 was installed to a depth of 114 feet and is hole below 15 feet of casing set into competent bedrock. However, the high levels of groundwater contamination noted in MW-4 in the glacial overburden precluded coring the rock.

The details of the rock coring and fracture analyses are discussed in Section 3, and the logs are presented according to the standard operating procedure for rock core log guidelines in Appendix 3.

2.5.5 Data Analysis and Presentation

The soil logs were installed in Geobase and cross-sections were produced are presented in Section 3. The cross-sections were plotted running from northwest to southeast, perpendicular to Highland Avenue. The cross-sections were spaced through the General Switch plant, through wells W-30 (Parella) and W-18 (Ruppert). One cross-section ran approximately parallel to Highland Avenue running through well W-18 (Ruppert) and W-32 (Stout), MW-2/MW-202, MW-18 and MW-11.

Data recorded on the rock coring logs included a description of the number of fractures per foot, lithology and orientation of the fractures and bedding planes. These data were used along with the geophysical logs to determine the location and depths of fracture zones through the study area. The soil boring logs and well construction details are presented in Appendix 3.

2.6 GROUNDWATER INVESTIGATION

The primary objective of the groundwater investigation was to indicate groundwater quality at the interface of the bedrock and the overlying glacial till (in samples from the shallow monitoring wells screened at the top of bedrock) and the groundwater quality through the profile of the shale aquifer in the top 100 and 200 feet of the aquifer (in the 200 series rock wells and the residential wells). Groundwater samples were collected during three phases of the investigation: during the 12-hour mini-pump tests of individual observation wells, before the pump test of well W-30 (Parella) and after that pump test. The samples were collected over a 4-month period in order to obtain information on groundwater quality in two separate seasons of the year. The water levels in these wells were compared and plotted to indicate the piezometric head in the shale aquifer and groundwater piezometric gradients that determine the horizontal and vertical direction of groundwater flow.

2.6.1 Installation of Monitoring Wells, 1992

There were eight existing groundwater monitoring wells at the site, MW-1 through MW-8, which were installed in 1984-85 by Fred C. Hart, as depicted in Figure 2-15. In order to more fully define the extent of groundwater contamination, a total of 14 additional soil borings and eight shallow unconsolidated monitoring wells were installed at the site during the RSAMP site investigation.

Only finely threaded joints were used on the casing, screen and riser pipe. Field welds are prone to leakage and were not used. No glues or oils were allowed during the drilling and installation of the wells. The riser pipes were permanently marked at the points surveyed. The wells were numbered clearly on the outer casing. A diagram of the rock well locations and details are presented in Figure 2-16. A detailed site map of the well locations is presented in Appendix 2.

2.6.1.1 Shallow Glacial Till Wells

The shallow glacial till wells MW-1 through MW-8 were installed in the vicinity of the soil contamination hot spots on the General Switch property where a plume of tetrachloroethylene exists. The wells were installed to the interface of the base of the glacial till and top of bedrock, encountered between 10 and 66 feet, to monitor the groundwater quality and flow at the till/bedrock disconformity. These wells did not penetrate the bedrock to avoid introducing any contaminants from the glacial till into the shale aquifer.

Three monitoring wells were installed during the RSAMP site investigation down-gradient of existing wells MW-3 and MW-4 and south of well W-30 (Parella). These wells were installed to the top of the bedrock at a depth of between 10 and 15 feet below the existing grade and were designated MW-9, MW-10 and MW-11.

Three monitoring wells were installed at a depth of between 15 and 23 feet, at the base of the glacial till in the hot spots TP-6, TP-A and TP-D on the General Switch property and were designated MW-16, MW-17 and MW-18, respectively.

The shallow, 4-inch-diameter monitoring wells were installed to a depth of between 5 and 35 feet screened across first water at the locations indicated in Figure 2-17 in accordance with Section 4 of the RSAMP. These wells, fitted with 10 foot-long-screens, were installed using hollow stem auger and wet or air rotary drilling methods.

A bottom plug was threaded into each screen. When the screen for each of these monitoring wells was initially placed into the borehole, it was held at the desired setting while an appropriately sized sand pack was added to the annulus around the screen. In accordance with standard USEPA procedures, each screen was sand packed from 1 to 2 feet below the base to 2 feet above the top of the screen. The sand-pack material was added to the annulus until the entire screen was surrounded and the sand had extended about 1 foot above the top of the screen. A 6-inch-to 1-foot-thick bentonite layer was then placed in the annulus and set directly on the sand pack. This bentonite seal assured that no grout material would percolate to the sand pack or enter the well.

The remaining well annulus around the riser pipe was grouted with an approved high-grade, sodium-based, granular bentonite/cement slurry mixture. Casing sealant and drilling fluids were mixed with potable water. All wells had an outer protective steel casing that was grouted into the ground surface with a concrete pad. The casing was locked, and most wells stick up 2 feet above ground. Wells in trafficked areas that were not subject to flooding were constructed in manholes flush with the ground.

Each well was fitted with an expandable rubber plug to prevent surface-water infiltration. In those wells with a stick-up casing, an air vent was drilled at the top of the riser pipe to allow the water level in the well to reach an equilibrium with atmospheric pressure. Figure 2-18 illustrates a typical shallow glacial-till monitoring well construction.

Accurate and detailed records of all well installation procedures were kept by the on-site geologist. These records include details on well materials, screen placement, location of couplings, riser pipe stick-up, sand pack, bentonite and grout placement and well development procedures. An as-built monitoring well log was prepared for each well. The individual well logs with well construction details are included in Appendix 3.

2.6.1.2 Shallow Rock Wells

Four shallow rock wells were drilled in an area where there was no known surficial soil contamination. These wells monitored the groundwater quality in the top of the shale aquifer in the vicinity of wells W-30 (Parella), W-32 (Stout), W-33 (Contel) and MW-17 (Barry) residential wells that have significant tetrachloroethylene contamination (Figure 2-19).

These four monitoring wells were installed adjacent to the existing residential supply wells. MW-12 was drilled adjacent to well W-30 (Parella) and was installed to 25 feet into bedrock. MW-13 adjacent to well W-32 (Stout), MW-14 adjacent to well W-33

(Contel) and MW-15 adjacent to well W-17 (Barry) were installed a minimum of 10 feet into bedrock.

Each shallow rock well was drilled with wet or air rotary drilling methods following the rock core pilot hole and was fitted with 10-foot-long, 4-inch-diameter polyvinyl chloride (PVC) screens installed to at least 10 feet into the bedrock. With the wet rotary drilling method, only a minimum use of potable water was used. Mud as an additive in the drilling fluid was used only in MW-14 when a poor seal was being obtained between the casing and the bedrock; drilling mud was used to grout the protective casing into the bedrock and prevent the leakage of formation waters past the casing.

During drilling the top of bedrock was found to be weathered and was susceptible to collapse in all shallow bedrock wells. Thus, the inner PVC screen and riser pipe kept the well free of debris. Each shallow rock well was constructed in a similar way to the shallow glacial till wells. These rock wells were nested adjacent to the open-hole residential wells and the water levels and groundwater quality were compared to measurements in the residential wells to define any groundwater contamination at the top of bedrock and indicate the vertical groundwater gradient at the site. Figure 2-19 illustrates a typical shallow rock well construction.

2.6.1.3 Deep Rock Wells

Four deep monitoring wells were installed adjacent to the existing shallow wells MW-2, MW-3, MW-4 and MW-7 (Figure 2-20). These wells were designated MW-202, MW-203, MW-204 and MW-207 and were installed to a depth of 100 feet below existing grade in order to obtain information regarding the extent of contamination in the shale aquifer. The drilling of the deep rock wells commenced on July 20, 1992, after the site stratigraphy was defined by the soil borings, the rock cores had been collected and evaluated, and the geophysics data had been reviewed to decide exactly where the wells should be placed.

Well MW-204 was drilled and sampled during both groundwater sampling rounds. This location was to be cored and pump tested. The well was on the periphery of the contaminated groundwater plume in the bedrock, and beneath significant groundwater contamination in the overlying glacial till. Thus, the USEPA agreed that the well should not be pump tested and the location should not be cored so as to prevent downward migration of the plume and any fragmentation of the DNAPL in the bedrock.

A separate permission was obtained to drill MW-204 in the wetlands. This delay in the drilling schedule extended the completion of the deep well installation for 1 month until August 31, 1992.

To install each deep bedrock monitoring well, a soil boring 12 inches in diameter was drilled 10 feet into rock by air rotary methods. An 8-inch-diameter casing was grouted into bedrock and grouted to the surface (Figure 2-21). The grout was allowed to cure for 24 hours before drilling resumed. After the grout had cured, rock coring was completed by coring with an N gauge core bit using wet or air rotary techniques (dependent upon hole conditions). Bedrock well installation was begun upon completion of soil sampling and coring into competent rock. The small-diameter sampling core hole, 2 inches in diameter, was grouted up and a new 6-inch-diameter open hole was drilled to a total depth of 100 feet using an air rotary technique with a 5-7/8 inch (nominal 6-inch) diameter downhole hammer or roller bit. Figure 2-21 illustrates a typical open hole, deep rock well construction.

2.6.1.4 Well Development

Well development was completed in order to achieve connection with the formation so that reliable groundwater data and representative groundwater samples could be obtained. All groundwater monitoring wells were developed as part of the well installation process. Prior to development of the monitoring wells, the bottom of each well was investigated to determine if DNAPL was present. Development was completed with a decontaminated submersible pump capable of producing a minimum of 2-gpm discharge with dedicated hose. The pump was lowered down the well in 20-foot increments to create a good hydraulic connection between the well and the aquifer in which it was screened. Well development was achieved by removing fine-grained geologic materials from the well screen sand pack and borehole wall. This was accomplished by removing sediment and water from the well. The development water from all wells was treated in the air stripper.

2.6.1.5 Well Surveying

Soil borings, monitoring wells, and residential wells were surveyed to determine a horizontal (location) and vertical (elevation) datum for inclusion in the base map. The outer casing, inner casing and ground level elevations were measured for each monitor well and for the residential wells depending upon their accessibility. This information may be found on the base map of the site in Appendix 1.

2.6.2 Groundwater Sampling

Following monitoring well development, two rounds of groundwater samples were collected (before and after the 3-day pump test of Parella) from 21 monitoring wells: MW-1 through MW-8 (existing), MW-10 through MW-18, and MW-202, MW-203, MW-204 and MW-207. MW-9 was sampled only once in June 1993. The samples were submitted for laboratory analysis for target compound list (TCL) volatile organic compounds by Methods 624 in accordance with contract laboratory program (CLP) protocols.

2.6.3 Groundwater Contour Maps

Water levels were collected and compared before, during and after the 3-day pump test of well W-30 (Parella). There was an approximately 3-week lapse between the two rounds of groundwater level readings. Water levels taken in the monitoring wells and water levels taken in neighboring wells were compared to define the potentiometric head in the three separate aquifers. The water levels were plotted to develop groundwater contour maps to obtain groundwater gradients to compute direction and rate of flow presented in Section 4.

2.7 POTABLE WATER INVESTIGATION

An investigation of the potable water in the residential wells was conducted. Two sampling rounds were conducted: one round before the long-term pump test of well W-30 (Parella), and one round after the pump test.

Samples were collected from 9 of the residential wells located on Highland Avenue which have historically shown tetrachloroethylene concentrations of 5 ppb or higher, as shown on Figure 2-22, Location of Contaminated Wells and Water Supply Lines, 1984. The wells sampled are W-27 (Robaina), W-18 (Ruppert), W-17 (Barry), W-32 (Stout), W-14 (Knapp), W-30 (Parella), W-8 (Osbourne), W-1 (Perez) and General Switch wells. These samples were submitted to the laboratory for TCL volatile organics by Method 624 and in accordance with CLP protocols. The Janiak, Lewis, Fiori, Lobb, Crooks and Cosmo Optics wells have been abandoned. Mr. Seeley died during this investigation and entry to his house was not possible during this investigation. Permission to sample well W-22 (Wand) was not obtained.

Samples were collected from residential wells located on Highland Avenue, Watkins Avenue and Electric Avenue which have historically shown tetrachloroethylene concentrations of lower than 5 ppb. These wells are: Nixdorf, W-19 (Rasmussen), Holmes, W-15 (VanPelt), W-11 (Gilbert), and Prior King Press. These samples were submitted to the laboratory for analysis for volatile organics by Method 524.2 (Revision 3) since a lower detection limit was required, which Method 624 was unable to provide.

2.8 WETLANDS DELINEATION

The wetlands delineation report, prepared by Eustance and Horowitz, delineated the wetlands area southeast of the General Switch facility. That report was submitted to USEPA and to Brian

Orzel of the U.S. Army Corps of Engineers, New York City, the week of June 29, 1992. A copy of the wetlands report is provided in Appendix 2.

The wetland data was submitted on forms entitled "Data Form, Routine On-Site Determination Method," that are the standard forms regularly submitted to the U.S. Army Corps of Engineers for freshwater wetland delineation. That agency has accepted these forms and has verified several of the delineations in the field. These particular forms show conditions at each edge location. Additional forms in the submission identify conditions at certain concentrated locations.

The various hydrophytic species were identified and indicator status was noted. The total percentage of dominant vegetation in the OBL, FACW and/or FAC categories was shown.

The investigation and delineation were completed during a period when standing water was observed on-site. Therefore, if the soil did not have water in an auger hole above 18 inches, this was taken as the normal distribution of the soil-water situation for the calendar year period.

The wetlands vegetation and characteristics were sporadic in this lowland area and because of the otherwise contorted wetland boundary, all stations were shown within the wetland boundary in order to be conservative in showing the wetland area. However, stations 1, 2, 4, 6, 7, 8, 10, 10A, 11, 11A, 13 and 13A do <u>not</u> meet all three wetland criteria. Station 3 is off of the site and next to a parking lot. Stations 5, 5A and 5B are adjacent to a parking lot. This parking lot edge was generally used as the wetland boundary. Station 9 is next to a street. The wetland boundary line was drawn outside of stations 8 and 10A, which do not meet all three criteria. This boundary line runs generally parallel to the upper contour and station 9A is within the boundary line. The wetland boundary line was drawn outside of stations 11A and 13, which do not meet all wetland criteria. This boundary line runs generally parallel to the upper contour and station 12 is within the boundary line.

Most of the sampling stations were upland sampling stations. Wetland delineation documents were provided for nonwetland areas.

Personnel from the U.S. Army Corps of Engineers were not asked to verify the delineation following receipt of comment No. 3 of the USEPA correspondence on August 12, 1992. This comment states that:

> "The report mentions the need for approval of the delineation by the U.S. Army Corps of Engineers (USACE). This rule however is subject to an exception. If the wetlands are

within the limits of a Superfund site, authorization by the USACE is not required."

Eustance and Horowitz had prepared jurisdictional request documentation dated June 12, 1992, for submittal to the USACE. This material was not forwarded to the USACE because of the comment quoted above.

Based on the information stated above in items 1-6, William Eustance, a qualified wetlands expert, submits that the proper data were submitted, that upland area information was shown and that further delineation or determination is not necessary. The wetland boundary was conservatively overstated in order to provide protection to freshwater wetland areas both within and outside of the project site.

2.9 SEWER SURVEY

At the end of July 1992, the City of Middletown repaved Industrial Place and the manholes designated for sewer sediment sampling were covered. Sampling of the sewer lines and storm sewers along Industrial Place was scheduled for September 7, 1992. Four sewer samples were collected on December 9, 1992. Three manholes adjacent to General Switch, one at the corner of Industrial Place and one adjacent to Lubricants Inc. had been paved over and were uncovered to perform the required sampling. The sewer manholes at the intersection of Highland Avenue and Industrial Place adjacent to Guild Molders were not located during two separate attempts and thus, no samples were taken at these locations.

There was no sediment build-up in the sewer lines. The flow had scoured out any sediments. The exact locations of the sewer sampling points are described in Section 5.

2.10 SURFACE WATER AND SEWER SAMPLING

Grab samples of surface water and sediment samples were collected in the wetlands to evaluate surface water quality southwest of the General Switch property. Surface water and sewer sampling is further described in Section 5.

Water and sediment samples were collected in the sewer line along Industrial Place and Highland Avenue according to the standard operating procedures presented in Section 6.0 of the RSAMP at the locations indicated on Figure 4-11 of RSAMP, Surface Water and Sewer Sample Locations. One manhole was located on Highland and Park Avenues, and three manholes were located on Industrial Place: the General Switch sewer line, the corner on Industrial Place, and the Lubricants, Inc., process sewer. The Guild Molders process water sewer line and the junkyard sewer manhole could not be found.

Surface water and sewer water samples were analyzed for volatile organics by Method 624 and sediments by Method SW846/8240.

2.11 PUMP TEST

Two types of pump tests were conducted on well W-30 (Parella) and the surrounding observation wells: a series of mini-pump tests to select the best observation wells and the later 3-day pump test of well W-30 (Parella). Three reports on these pump tests have been submitted to USEPA and are summarized in Section 4.

2.11.1 Selection of the Observation Wells

To select the best observation wells for the long-term pump test of well W-30 (Parella), initial short-term step drawdown tests were completed in two phases. During the first phase, the existing wells of W-30 (Parella), W-8 (Osbourne), W-18 (Ruppert), W-17 (Barry), W-1 (Perez), W-33 (Contel) and W-31 (Electra Manufacturing) were pumped. During the second phase, monitoring wells MW-203, MW-207 and MW-202 were step tested. The wells selected in the first phase were existing wells that in the Survey of Wallkill Wells indicated yields above ½ gpm and were spaced so as to provide coverage of the whole study area.

During the step drawdown tests, the performance characteristics of each potential observation well were determined. Data that were obtained concerning the observation wells included the depth and condition of each well and the static water levels along Highland Avenue immediately prior to the pump test. The yield of each well provisionally selected as an observation well was determined
in order to assess the degree of hydraulic connection these wells have to the regional fractured bedrock aquifer.

The wells selected for observation wells were those that have demonstrated communication with the major fractures of the shale aquifer by showing a significant inflow of water into the well at rates approaching 2 gpm during the short-term pump tests and a demonstrated effect in drawing down neighboring wells, including well W-30 (Parella).

2.11.2 Pump Test of the Parella Well

Section VII (A) of the Consent Decree states the primary objective of the pump test was as follows:

> "The pump test shall be performed for the purpose of demonstrating that the Parella well is satisfactory for interception (through pumping capture) of the contaminant plume underlying or near the site."

The complete details regarding the 3-day pump test are contained in Section 4.0.

During the pump test, water levels were taken to determine the effect of pumping W-30 (Parella), on the surrounding wells screened at the top of bedrock, the residential wells on Highland Avenue and selected observation wells around well W-30 (Parella) and on the General Switch property.

During the 3-day pump test of well W-30 (Parella), contaminated groundwater was pumped from well W-30 (Parella) to the air stripper. The air stripper treated the groundwater to remove volatile organics.

The rate and amount of groundwater withdrawal and treatment were monitored with periodic reading of the flow meter and totalizer fitted to the discharge of well W-30 (Parella). The pumping rate was double checked with measurements with a pre-calibrated bucket and a stopwatch at the treatment storage tanker.

The operating parameters of W-30 (Parella) pumping well were determined in terms of optimum pumping rate, yield and specific capacity of the well. The 3-day pump test report presents details of the depth and condition use of W-30 (Parella) pumping well including static depth to water, well volume, depth of pump, pump capacity, power supply and pump control devices.

2.11.2.1 Aquifer Characteristics

By observing the response of the aquifer while pumping well W-30 (Parella), the aquifer characteristics of transmissivity and storage in the shale were obtained and the long-term performance of well W-30 (Parella) was observed.

The yield data obtained during the step drawdown tests of the prospective observation wells located across the study area indicated where high-yielding wells are located. These details, when combined with the information gathered during the geophysics study, indicate where the major regional fractures may be located.

2.11.2.2 Assessment of the Parella Well as a Recovery Well

By measuring any drawdown in the wells surrounding well W-30 (Parella), the long-term pump test of well W-30 (Parella) determined that the capture zone of well W-30 (Parella) alone will not encompass the tetrachloroethylene plume observed in homeowners' wells sampled prior to the pump test. Additional pumping wells are required to clean up the aquifer. One round of water samples was taken from the observation wells surrounding well W-30 (Parella) prior to the pump test to establish the extent of contamination in the shale bedrock aquifer and one round after the pumping to assess the water quality changes caused by the pumping.

Water level measurements were taken to determine the interconnection of the glacial till and the shale wells. By comparing the response of shallow and deep wells nested adjacent to each other, the degree of interconnection of the glacial till and the bedrock aquifer was assessed.

An attempt was made to limit the use of nearby wells during the pump test because interferences and additional drawdown could result from any use of nearby wells. This was not anticipated to be a major concern because no wells on Highland Avenue between Park Avenue and Industrial Place are currently used for drinking water supply.

One of the proposed remedial actions involves flushing contamination from the hot spots of soil contamination through the glacial till to the bedrock aquifer. The shallow unconsolidated wells were monitored during the pump test of well W-30 (Parella) to determine if pumping the bedrock aquifer draws down the water levels in the glacial till. In this way, the degree of interconnection between the till and the fractured bedrock aquifer was evaluated. Section 4 contains further details of the hydrogeology of the site.

2.11.2.3 Method of Pump Test Analysis

The study area is underlain by fractured bedrock composed of sandstone and shale of the Austin Glen series. The bedrock acts as the primary aquifer in the area and is overlain by glacial till material of low permeability. Based on earlier pump test results and subsequent subsurface investigations, it appears that groundwater flow direction is influenced by the fractures and the overlying glacial till which acts as a leaky confining layer. The methods of pump test analysis were determined by the nature and type of aquifer response under pumping conditions.

In many instances, aquifers may be considered homogeneous, but not isotropic. Aquifers whose permeability varies in different directions are classified as anisotropic. Significant anisotropy may occur in fractured bedrock and could have a major effect on the groundwater flow pattern.

Pump test data, analytical results from on-site monitoring wells and data from subsurface investigations indicated that initial linear flow during the pump test was noted to well W-30 (Parella) but radial flow seems to control the flow to well W-30 (Parella) on a regional scale. The evaluation of the pump test data is presented in Section 4.0.

2.12 AIR INVESTIGATION

2.12.1 Air Monitoring During Operation of the Air Stripper and Analysis During Pump Tests

The water generated during the pump tests necessitated treatment prior to discharge. This treatment was accomplished with a Merry-Go-Round air stripper, which is described earlier in this section. The air exhaust from the air stripper underwent treatment with activated carbon prior to discharge into the atmosphere. During the operation of the air stripper, air samples were collected from the air stripper exhaust (following treatment) by direct injection into the Photovac 10S50 gas chromatograph for field analysis. According to the Consent Decree, if the concentration of tetrachloroethylene in the air stripper exhaust (following treatment) exceeded 1,000 micrograms per cubic meter (ug/m^3), the system was to be shut down and reevaluated. Samples of air were taken between two carbon filters on the air stripper; when breakthrough was observed the system was shut down and the carbon was replaced. Thus, there was always a clean backup carbon filter prior to discharge and no emissions were noted from the air stripper. In addition to the field analysis, one air sample was collected each day between the carbon filters and was submitted to the laboratory for analysis by USEPA Method TO1.

The requirements of the New York State Air Emission Standards for Volatile Organics (6 NYCRR Parts 205, 212, 232-234 and existing Air Guide I) were complied with during this short-term air stripper operation. The operation of the air stripper is further discussed in Section 6, Pilot Testing.

2.12.2 Air Monitoring during Investigative Activities

Air monitoring was conducted during field activities utilizing a photoionization detector (PID) to determine the levels of hazardous or toxic vapor/gases. When volatile organic compounds were detected above 10 ppm in the air during the drilling of observation well OB-9 at the rear (north) door of the General Switch building during the field activities, appropriate procedures including isolation of the site and wearing air purifying respirators, were implemented as indicated in the site Health and Safety Plan.

2.13 SOIL VAPOR INVESTIGATION

NYSDEC has expressed reservations about the soil remediation alternative of soil flushing because soil flushing could cause the migration of contaminants into uncontaminated zones of the groundwater. In addition, there have been major technological advances in soil vapor extraction since the Consent Decree was entered into 1989. For these reasons, it was proposed that an investigation of soil vapor extraction be conducted. The vapor extraction pilot study conducted at the site is described in Section 6.0.

2.14 CONTINGENCIES FOR THE INVESTIGATIVE PROGRAM

2.14.1 Contingencies for Groundwater Level Changes

Some homeowners reported that during settlement of this area, as more wells were installed along Highland Avenue, the water level in the shale aquifer dropped approximately 20 feet, necessitating the drilling of deeper wells to reach groundwater. This overpumping of the resources of the shale aquifer has ceased, and groundwater levels may now be recovering. There were indications that the groundwater table has risen along Highland Avenue since the residential supply wells were replaced by a public water supply. Herman La Forge a local plumber who services the wells in the area, has indicated that the water level in well W-8 (Osbourne) has risen by 20 feet.

This anticipated rise in the water table did not affect the installation of the monitoring wells because the rise occurred after the residences were supplied with city water and the aquifer should have time to achieve a static condition.

2.14.2 Contingencies to Optimize Data Obtained

The soil borings and monitoring wells were installed to provide a range of concentrations of anticipated soil and groundwater contamination. The following contingency plans were used to optimize the usefulness of data obtained from the soil borings and monitoring wells:

- The soil borings were sampled and analyzed on site for volatile organics using a Photovac 10S50 gas chromatograph. The results of this field screening were used to direct the subsequent field work and well installation. Prompted by Photovac data, soil boring SB-24 was installed as an additional boring to define the extent of contamination southeast of TP-D. Soil boring SB-12, where contaminated soils were encountered was completed as a vapor extraction well (MW-18) screened in the unsaturated zone above bedrock.

  All coring into the rock at TP-A, TP-D and TP-6 was performed through a casing grouted 5 feet into the top of bedrock. All soil borings were grouted up so as not to provide a conduit for the percolation of contaminated water. An additional vapor extraction well, VES-2, was installed in order to determine the vapor concentration in the soil at TP-D and to support the evaluation of the appropriate cleanup methods including vapor extraction, if needed at a later date at TP-D. This well was screened through the water table, contained more water than MW-18 and was subsequently used as a monitoring well. Vapor extraction well VES-2 was sealed with a locking airtight cap and will be a permanent groundwater monitoring well, and MW-18 will be used for vapor extraction if needed.

2.14.3 Pump Test Contingencies

It was anticipated that the capture zone created by pumping well W-30 (Parella) would encompass all previously contaminated wells and have a significant impact upon groundwater flow in the area of the General Switch. However, pumping the well W-30 (Parella) alone will not attain this objective. Therefore, the data on the pumping efficiency of the observation wells and the aquifer characteristics, obtained during the step drawdown tests of the adjacent residential and deep bedrock monitoring wells, and the pump test of well W-30 (Parella), will be used to formulate a plan presenting a network of pumping wells capable of capturing the whole plume.

2.14.4 Free Product (DNAPL) Recovery

The potential for severe environmental impact is likely from free product that was detected in deep bedrock well W-30 (Parella). One gallon of free product has the capacity to contaminate 200 million gallons of fresh water. Upon detection of free product in well W-30 (Parella), a free-product recovery system was immediately installed.

Tetrachloroethylene is heavier than water (specific gravity 1.63 at 20 degrees Centigrade) and thus the free product sinks to the bottom of well W-30 (Parella).

The well was provided with a recovery pump that has a conductivity probe that senses the accumulation of nonconductive product. When water is displaced from the bottom of the sump, the Model 2010-02-DA pneumatic piston recovery pump is turned on to remove the product from the bottom of the well (see Figure 2-23). The pump intake is on the bottom of the pump and is set to cycle in response to ¼-inch increase in product level at ½-inch above the bottom of the sump. The product storage tank is fitted with a product high-level cut-off that shuts down the system when the tank is full of product. The product recovery system was inspected each day for the first five days of operation, then each week for four weeks, and monthly thereafter.

2.14.5 Merry-Go-Round Air Stripper

Contaminated water generated during groundwater-related activities were treated by the Merry-Go-Round air stripper deployed on site.

Groundwater for treatment was first stored in a storage tank adjacent to the stripper. The tank acted as an equalization tank by evening out peaks in the influent concentration and the system was piped to allow recirculation between the tank and the air stripper. This recirculation of the treated groundwater allowed multiple passes of the treated groundwater and operation of the air stripper at 15 to 20 gpm while the discharge rate was usually between 4 and 8 gpm.

Hook-up of the air stripper to the tanker was begun the week of June 15, 1992. The first use of the air stripper was begun on June 28, 1992.

The operation of the air stripper is further discussed in Section 6.0, Pilot Studies.

2.15 DATA VALIDATION

Data validation of the laboratory analyses data was performed by Environmental Compliance Monitoring, Inc. (ECM). A full complement of currently available data validation logs are presented in Appendices 3 and 4. Some data sets are currently undergoing data validation.

According to ECM's data validation reports, all samples in General Switch were analyzed in accordance with USEPA (3/90) CLP Protocol. Minor non-conformances were reported. In some cases the original analyses were done within required holding time, but the re-analyses of diluted samples were performed one or two days past the holding times. Instrument calibration criteria were exceeded during certain analyses. As reported in the data validation, these non-conformances should have minimal effect on the data quality. Based on the data validation, data qualifiers are currently being added to the data summary tables presented in Appendix 5.

SECTION 3

CONTENTS

3.0 SITE GEOLOGY AND HYDROGEOLOGY

3.1 REGIONAL GEOLOGY

The Middletown area lies within the physiographic province known as the Valley and Ridge province. The area is underlain by alternating layers of hard sandstone and soft shale that were compressed and deformed by regional tectonic pressure exerted form the southeast. The deformation occurred in the Taconic Orogeny, approximately 450 million years ago. As a result of pressure from the southeast, the long axes of the folds in the rocks trend northeast to southwest.

The stratigraphic units underlying the northwestern section of Orange County are part of the Normanskill Shale unit. The lower member of the Normanskill is the Mt. Merino Shale, and the upper member is the Austin Glen Grit and Shale. The combined thickness of these two members is thought to be between 8,000 and 9,000 feet. Stratigraphically above the Normanskill Shale is the Snake Hill Shale.

Lithologically, the lower part of the Mt. Merino Shale is composed of medium-dark gray mudstone layers interfingered with layers of fine sand and silt. The upper part of the member is composed of thicker, more massive beds of laminated sandy silt-stone and finer layers of mudstone. The overlying Austin Glen member is composed of interbedded, massive dirty sandstones or graywackes and thinly-bedded fissile shales. Graywackes sections of the Austin Glen are medium gray and typically weather to a buff color with a ½- to 1-inch rusty-brown rim that is slightly porous.

The site is located on the northeast limb of a major anticline formed of the Austin Glen Grit and Shale (the Shale) that consists of interbedded massive sandstones grading with increasing micaceous minerals through siltstone and graywackes to thinly-bedded fissile shales (see Figure 3-1, Regional Geological Map). The strike of bedding for the Austin Glen Series is northeast-southwest and the regional dip is 16-40° northwest, observed in local outcrops on Industrial Place that cut across the southern perimeter of the study area, and regional dip is indicated in the cross-section included with the Goshen Quadrangle Map (Ref: Frimpter, M.H. Groundwater Resources of Orange and Ulster Counties, NY, U.S. Geological Survey Paper - 1985).

As noted in outcrops on Industrial Place to the south of General Switch, there is no primary porosity in the massive sandstone, and shale exposed in that the rock is consolidated and the rock fabric is tightly cemented. However, the Shale is cut through by regional fractures that transect the bedrock. The fissile, weathered Shale is observed along the railroad grade to the east of General Switch while the more massive sandstone, fractured with regional fissures, is seen immediately to the southeast at Lubricants, Inc. The trend of the regional fissures at the Lubricants outcrop is predominantly northeast-southwest. However, a second set of fissures trend southeast to northwest and, intersecting the primary fractures, break the rock into rectangular blocks.

In the fall of 1992, further information regarding the trend of the regional fractures was obtained from a Geonics EM-34 Terrain Conductivity Meter survey conducted by Delta Geophysics. The EM-34 was used to gather conductivity data (milli-ohms/m) at 20-foot intervals along transect lines spaced 40 feet apart. A coil separation distance of 20 meters was used, and data was gathered in both the horizontal and vertical dipole modes. This configuration allows gathering of data to two effective depths of 45 feet (horizontal dipole) and 90 feet (vertical dipole).

The area where the geological survey was conducted is depicted in Figure 3-2, Site Map With VLF Survey Area, and the Geophysical Base Map in Appendix 2. The survey was extended in the area of the Hebrew School to investigate a suspected fracture trending from W-18 (Ruppert) and W-17 (Barry) wells toward well W-19 (Rasmussen), identified in the field by drawdown of well W-19 during the 12-hour pump test of well W-18. The data for each station was plotted at the mid-point of the transmitter-receiver coils.

The EM-34 was susceptible to cultural interferences, which were numerous in the residential areas of the site. The major interferences included various underground pipes, overhead power lines, buildings, and the electrical substation at the rear of General Switch. Possible metal debris buried in the fill material southwest of the General Switch building also influenced the EM-34 to a lesser degree. Various metal objects are visible at the surface throughout the site that may have affected the readings obtained.

The geophysical anomalies detected by the EM-34 investigation have been plotted on the large scale Geophysics Map presented in Appendix 2 and on the attached map (Figure 3-3) which is a part of the large scale map and shows the area of particular interest between General Switch and well W-30 (Parella). Linear trends interpreted from the aerial photos are also shown.

The EM-34 data pointed out several linear trends between General Switch and well W-30 (Parella), which are shown as shaded areas on Figure 3-3. Dashed lines indicate that the trend is inferred or faint. These trends may indicate fractured rock, linear trends in the rock surface (such as troughs), or linear trends in the overburden. Several EM-34 linear trends correspond to trends observed in the aerial photos. These trends are oriented northeast-southwest, which corresponds to the regional fracture pattern. There is a major fracture identified in a northeast-southwest trend, southwest of the Orange and Rockland substation. The corresponding EM-34 trend of low conductivities is not shaded for clarity.

The primary fractures trend about North 55° East (N 55° E), with secondary fractures, visible to the northeast (NE) of the site area, trending North 44° West (N 44° W). Several north-south (N-S) trends are observed in the EM-34 data which do not seem to correspond to the regional secondary fractures seen in the aerial photos. These north-south trends may be related to the second set of intersecting fractures noted in the Lubricants Inc. outcrop. The glacial activity in this area may have eroded such north-south linear features.

Two linear trends run from the rear of General Switch to the south of well W-30 (Parella). Linear Trend A runs close to MW-2 and MW-202. At grid location K-520', a strong anomaly is indicated by the EM-34 data and again 40 feet to the west. This may indicate a more fractured zone running in the line of the air-photo linear trend A. The deep well, MW-202, was located 20 feet north of MW-2 to pinpoint the strong anomaly that was noted in the aerial photographs.

The locations of MW-7 and MW-207 are not near any obvious major linear anomaly. The site selected for the field permeability testing of the glacial till was adjacent to well W-31 (Electra) and was located away from any major anomaly.

The EM-34 survey also recorded an area of low conductivity adjacent to and in the wetlands, where a concentration of 15 ppm total volatiles was found in MW-4, and reported in the Fred C. Hart study.

3.2 SITE HYDROGEOLOGY

The stratigraphy of the site is a silty glacial till overlaying a sandstone and shale formation: the Austin Glen Series. From profiles of the soils at these locations, it can be noted that the soil horizons of the Washington Heights section of the Town of Wallkill belong to the Mardin gravelly silt loam series (Reference 3: Orange County Soil Survey). The Mardin soils are formed from a gravelly, sandy silt glacial till which in turn is derived from the sandstone, shale and slate of the bedrock of this area. The unconfined till lies on the Austin Glen Grit and Shales.

There are two soil types of glacial till under the property. An orange-brown glacial till consisting of fine sand and silt is generally found near the top of the soil profile. The till tends to become more clay-rich and the boulders increase in abundance with depth. Below this brown till is a gray clay till layer containing abundant fractured shale fragments that overlies the fractured shale bedrock. In the soil borings drilled in the Fred C. Hart study and in the Shakti site investigation, the glacial till in the General Switch area was found to be fairly consistent in color and texture. In all soil borings, at least 1 to 2 feet of fractured and weathered shale were encountered on top of fresh, gray shale bedrock. The rock cores and geophysical logs showed that the gray shale was frequently interfingered with a harder, slightly coarser siltstone or graywacke unit.

The building of General Switch sits upon fill, and the parking lot to the southeast of the facility is composed of fill that contains some metal objects and is in part reworked till that contains cobbles. The three principal soil and rock types, the fill, glacial till and bedrock, are discussed in detail in this section. Information from previous investigations has been used to add detail to the description.

Fill

As observed in the soil borings, the fill under the General Switch property consists principally of reworked glacial silty clay till containing broken shale and rounded cobbles and boulders. The thickness of the fill varies from a few inches on the north of the building, where the footings of the building rest on native glacial till, to 10 to 12 feet in soil borings SB-8, SB-9 and SB-10. The fill forms a wedge under the building and in SB-24 accounts for the 10 feet of elevation of the southern parking lot. There is a change of slope at the edge of the fill immediately to the south of SB-24, but the fill is noted as spoil at the foot of the slope into the wetlands that is 3 feet thick in SB-14 at the site of monitoring well MW-16. The fill tapers off to nothing 20 feet from the toe of the slope, where native till was observed at the surface.

A magnetometer survey conducted by Fred C. Hart Associates in 1984 identified four major magnetic anomalies in the fill of the parking lot.

The contour map constructed from the magnetometric data collected in the field is shown in Figure 3-4. Four major magnetic anomalies were identified on the magnetometric contour map as well as the magnetic gradient generated by the reinforced concrete wall of the plant. The largest anomaly, labeled 1, is located in the General Switch parking lot and anomalies 2, 3 and 4 are scattered around the study area. In the parking lot, ambient gradients produced by the concentrated layer of buried metal precluded accurate modeling. Anomalies mapped in other areas of the General Switch property may be due to the highly magnetic nature of glacial till. Test pits were dug in each of the four locations and metal objects were found in two of the pits.

The only area where shallow buried metal was located with the metal detector was in the General Switch parking lot. The locations of these sites (labeled MD-1 through MD-7), as well as surface metal locations, are shown in Figure 3-5. Sites MD-1 through MD-7 correspond to the area where scrap metal was found when the test pits were dug. The scrap metal layer is actually continuous in that part of the parking lot, but the metal detector only identified scrap metal that was 4 feet or shallower. Most of the surface metal found at the site was also in the vicinity of the parking lot. The large area of surface metal near the present loading dock consisted of trolleys, several old generators and a compressor. The scrap metal on the southeastern edge of the parking lot consisted of metal shelves, a refrigerator, some fence wire and several drum lids. Several empty paint cans and an empty drum were also found along the southwestern edge of the Parella property (320 Highland Avenue).

To further investigate the fill and surficial soils in the parking lot, test pits were dug during the Fred C. Hart study in each of the four locations, and metal objects were found in two of the pits. The metal objects buried in the parking lot were trolleys, several old generators, and a compressor, as reported in the "Hydrogeologic Investigation of General Switch Site," Fred C. Hart Associates, November 1984.

Twelve test pits were dug to provide both visual and physical data about shallow subsurface conditions at the General Switch site. Samples were collected from each pit to provide data on grain size, permeability and the extent of tetrachloroethylene contamination. In addition, several test pits were located in areas where magnetometry or metal detection data indicated that buried metal might be present.

The backhoe operator excavated 10- to 12-foot pits at each of ten predetermined sites (Figure 3-6). The sites were chosen on the basis of data gathered in the preceding magnetometry, metal detector and organic vapor analyzer (OVA) surveys. Areas where particularly high levels of volatile organics or metal were found or areas where the topography was unusually disturbed were chosen as sites for test pits. An additional two sites were also dug to collect bulk soil samples for permeability tests. VOA headspace screenings and analyses were performed in the evening a maximum of 12 hours after the samples were collected. The chemical data from the headspace analyses is included in Section 5. All the pits were backfilled after sampling and test pit logs were completed.

The test pit logs completed for all twelve test pits are contained in Appendix 3. Although the soil and till thicknesses were somewhat variable, the units themselves were quite similar across the study area. The topsoil tended to be dry and brown in color and ranged in thickness from 5 inches in undisturbed areas to 5 feet in disturbed areas. Some of the topsoil on the Parella property (320 Highland Avenue) had been bulldozed into high piles that supported thick stands of vegetation.

In three of the four test pits dug in the parking lot (TP-2, TP-6 and TP-10), an extensive scrap metal and industrial waste layer was encountered. The OVA readings in these pits were some of the highest measured and it was frequently possible to smell a "chemical" odor. The industrial waste found in the test pits included: paint cans, drum lids, metal switch boxes, paint sludge, wire screens and wood. One empty drum was found in TP-2 and two drums, partially filled with gray paint sludge, were found in TP-10 at a depth of 5 to 6 feet. Neither of these drums had lids and the gray paint sludge was dried and crumbled. Test pit TP-6 was dug on the southeast side of the parking lot and also contained industrial waste. The "chemical" odor was strongest in this test pit which was located directly across from the loading dock. Test Pit TP-9 was the cleanest pit in the parking lot and contained mostly soil fill material rather than industrial waste. One half of a drum, with cleanly cut sides, was found in the study area at TP-3. The drum was screened with the OVA, which did not detect any volatile hydrocarbons in the drum.

Glacial Till

The soil borings provided information on the extent and thickness of the glacial till, as well as the location and nature of the underlying bedrock surface. All the soil borings were terminated on top of bedrock. In addition, grain size and chemical analyses of split-spoon samples provided information on the extent and possible paths of migration of the solvents including tetrachloroethylene.

On top of the shale and sandstone bedrock, there is a veneer of glacial till that is between 7 and 108 feet deep under the site. This glacial till has accumulated across the hillside of Washington Heights on top of the shale and sandstone bedrock. The bedrock has a significant influence upon topography. The topography of the site follows the general trend in the top of bedrock under the site and drops in elevation into the wetlands and falls away down Highland Avenue to the northwest.

There are two distinct till layers on site. The upper till that is present.in all soil borings is orange-brown in color and predominantly silt and clay-rich, with occasional fine to medium sand pockets and gravel zones, and abundant cobbles and boulders scattered throughout the till. The boulders are mostly shale in composition and tended to be angular. The till tends to become more clay rich with depth and the lower till is a gray silty clay till, with numerous angular shale boulders and cobbles. The gray till rests uncomfortably on the bedrock.

The three-dimensional plot in Figure 3-7 was developed from the elevation of the top of the shale in the boreholes and along with four cross-sections of the site presented in Figures 3-10 through 3-13 indicate that the top of bedrock along Highland Avenue slopes down to the southwest.

At the intersection of Industrial Place and Highland Avenue, under the Perez property (338 Highland Avenue) to the north of the site there is approximately 14 feet of glacial till at MW-8. This veneer of glacial till deepens to 31 feet to the southwest down Highland Avenue under the Parella property (320 Highland Avenue). Further down Highland Avenue, under the Stout (316 Highland Avenue) and Contel (306-314 Highland Avenue) properties, the glacial till is between 53.5 and 64 feet deep as indicated in the soil borings SB-17 and SB-18. The bedrock surface rises to 45 feet deep under the Barry property (309 Highland Avenue) before dropping off precipitously to 108 feet deep at the Hebrew School.

There is 15 to 23 feet of unconsolidated material under the General Switch building, as indicated in Figure 3-10. The general trend is for the topography and bedrock surface to drop 25 feet from MW-1 into the wetlands and rise again to form an outcrop adjacent to Lubricants Inc. The wetlands below General Switch have been formed in this trough.

As indicated by the soil borings presented in Figure 3-10, there is an apparent bench in the top of bedrock below the General Switch parking lot that is oriented in a northeast-southwest direction. The unconsolidated soils resting on the bench under General Switch at the rear loading dock consist of 8 to 10 feet of silty clay till with frequent boulders over 15 feet of clay rich silty sand till that is very dense and contains numerous rounded and angular cobbles.

This bench on the top of bedrock under the General Switch building slopes down to the west into the trough running under the wetlands, through MW-2 and trending southeast to northwest, as shown on Figure 3-8. This trough is again observed along Highland Avenue between the Stout (316 Highland Avenue) and Contel (306-314 Highland Avenue) properties, as indicated in Figure 3-13.

Figure 3-7 indicates that the bedrock drops 15 feet between MW-11 and MW-6. We have superimposed the cross-section between MW-11 and Lubricants Inc., where the bedrock rises to elevations above

625 mean sea level (MSL) to demonstrate that the wetland to the south of General Switch is formed in a hollow on top of bedrock and that groundwater runoff will accumulate in this depression. The water table in this depression was between 8 and 11 feet below ground in MW-11 and MW-6 and thus any precipitation would tend to collect and infiltrate into the bedrock at this location.

The trough lies approximately parallel to the long axes of folds in the area, and may have originated as a structurally weak area that was subsequently traversed and scoured out by glaciers. This structural feature may have channeled the DNAPL that infiltrated through the soils under the General Switch site to move to the northwest in the direction of well W-30 (Parella).

All the split spoon samples taken in the till were relatively dry. Samples from shallow depths tended to be very dry and those from deeper in the till were slightly moist. Moisture content increased with proximity to bedrock, but no saturated till sample was found in any test boring. The till in the study area ranges in thickness from 5 feet to 108 feet and generally thickens toward the west. Thus, the top of bedrock slopes in the opposite direction to the topographic slope of the hillside of Washington Heights. The hillside does not have a central core of rock and in fact the bedrock is closer to the surface in the wetlands below General Switch.

Permeability in the upper soil zones formed from the till is described in the literature as moderate in the surficial layer and upper part of the subsoil and is slow or very slow in the underlying substratum. The till below the upper soil zones is generally unsorted and unstratified and consists primarily of clay, silt and boulders. The permeability of this till is very low; the permeability values range from 1.3×10^{-7} cm/sec to 6.4×10^{-7} cm/sec. (Reference 3: Orange County Soil Survey and Reference 4: Frimpter, M.H. Groundwater Resources of Orange and Ulster Counties, NY, U.S. Geological Survey Paper - 1985).

Additional physical soil testing was completed in 1985 by Fred C. Hart to evaluate the permeability of glacial till at the General Switch site using three methods. Direct measurements were made by tests on bulk soil samples and by slug tests. An indirect assessment of permeability was also made using grain size analyses. This information has been used to evaluate the potential for contaminant migration through the till. The low permeability of the till to water is not a good measure of the permeability of the till to movement of solvent. The solvent has the ability to shrink the clay and develop its own fissures. In Sections 5 and 7 evidence of the extent of contamination is presented indicating the solvent has passed through 23 feet of clay till to reach the bedrock and well W-30 (Parella).

One limited in-situ well slug test was performed on monitoring well MW-5. Well MW-5 was chosen for the slug test because it was a dry well and could not be sampled.

The results of the grain size analyses conducted by Fred C. Hart are presented graphically in distribution curves contained in Appendix 3. An examination of this data indicates changes in the grain size distribution with depth and some variability from test boring to test boring. In TB-8, all five samples ranging in depth from 2 to 14 feet contain approximately 50 percent clay, and there is only a small amount of variability with depth. In TB-5, the amount of clay in the samples ranges from 20 to 30 percent and there is more variability with depth in these samples than at other locations. However, the samples get slightly coarser with depth. In TB-2, where the samples range in depth from 0 to 32 feet, there is a considerable amount of variability in the grain size distribution. The amount of clay in the samples ranges from 12 to 70 percent with clay-rich samples coming from the intervals of 10-17 feet and 28-32 feet. In a general sense, the samples get slightly finer with depth.

Only two of the three bulk soil samples collected for triaxial permeability tests could be used. All of the samples were of questionable quality because of the friable nature of the till and the cracks that had developed due to digging, handling and lab trimming. However, tests were run on sample 11 and sample 12A. The results of the test indicated a permeability of 1.3×10^{-7} cm/sec in sample 11 and 6.4×10^{-7} in sample 12A. These values may be slightly high because the samples were first saturated and because of the small cracks and fractures that were artificially introduced into the till before the test was performed. The original data and summary sheets are contained in Appendix 3. These values are fairly typical of glacial till in the northeastern United States, and the till may be described as having a very low permeability (Terzaghi and Peck, 1967).

The data from the falling head and constant head tests is shown in Table 3-1. Permeability values could not be calculated because the data indicates that the gravel pack and the till surrounding MW-5 remained unsaturated. The unsaturated nature of the till is shown by the fact that the length of time it took to add one gallon of water to the well consistently increased in the constant head tests. Furthermore, if the till had been saturated, the results of the falling head tests would have been more similar. The very low permeability of the till made it impossible to saturate the till or use the results of the slug test.

Available water capacity in the till is low. A perched water table has been observed in the months of November, December and January in the top of the till. This perched water table was noted in the till that is tapped by poorly yielding dug wells: on the Contel property (306-314 Highland Avenue) (abandoned), on the Stout property (316 Highland Avenue) (abandoned), and at 208 Watkins Avenue (used for watering vegetables). When the Technical Assistance Team first arrived on-site on October 15, 1983, a survey of wells near well W-30 (Parella) was made. Two shallow dug wells were noted on the property belonging to Janice Stout (Stout Lot #4). The two wells were 11 feet and 16 feet deep, were dug into the glacial till soils, and were dry to the bottom. Following a major storm event, the water levels were measured on December 16, 1983. Within a 2-day period, water had reached to within 1 foot of the ground surface. The water levels in these wells then continued to hold a level within 2 feet of the surface through November, December and January. Water was found consistently through these winter months to be close to the ground surface in the shallow dug wells on Commonwealth, Watkins and Highland Avenues as well as in sumps and depressions along Industrial Place Extension. This perched water was noted filling the dug wells in the winter. The water levels in these dug wells were observed to fall through the summer months. The adjacent deep wells, between 40 and 250 feet, tapping the shale aquifer had water levels between 10 and 20 feet below the perched water levels in the till in the shallow dug wells, as reported in the Pump Test Tables 1, 2 and 3 and in the Summary of Water Level Measurements, 11/15/83 to 2/3/84.

Transmission of water and contaminants through the glacial till is likely to be retarded by the slow percolation rate operating in the surficial till. Based upon observations from the soil borings in the Fred C. Hart study and in the Shakti study, it is probable that no significant water occurs in the interior of the glacial till.

The water levels in most of the wells (excluding MW-5 and MW-8) slowly recovered after well development. This recovery indicates that either water is flowing horizontally through the till or water is leaking upward from the bedrock into the well screen. The hydraulic heads in MW-2 and MW-7 are fairly high and it seems more likely that water is leaking from the bedrock.

Permeability Testing

An infiltration permeability test was completed in 1992 to determine the amount of groundwater that the glacial till will allow to percolate through the soil profile and into the shale aquifer.

A test pit was excavated in clean soil remote from the hot spots defined on the General Switch property. The location was 20 feet from shallow monitor well MW-1 screened at the base of the glacial till and 20 feet from W-31 (Electra) deep bedrock well.

A constant head test was conducted in which the water level was kept constant by continually adding water, and the amount of time it took to add a certain volume of water was recorded. The response of the water levels in the surrounding shallow and deep monitoring wells to a known surcharge volume of water was measured over the ensuing 24 hours. No change was observed in the water level during the test and no response was observed in MW-1 or W-31.

Water Level Measurement and Flow in the Glacial Till

In 1983-1984, surface water was observed to collect in shallow dug wells and in depressions throughout the site area. The water levels noted in the dug wells in the top of the till follow the topography of the site. At approximately the 600-foot piezometric contour, this surface water was observed to collect at the base of the hill, forming a wetland in the valley bottom as noted on Figure 3 of the 1984 Hart report. In light of the low permeability of the till, it is likely that precipitation predominantly runs off by overland flow following the topography into the wetlands along Industrial Place. Groundwater elevations on figures and tables are expressed in terms of mean sea level elevations.

In the General Switch area, the till is acting as a confining layer and from observations during the soil borings there is no true water table aquifer in the shallow till soils at the site. The water noted in the dug wells is precipitation collected in these isolated sumps in the surficial till. This conclusion is substantiated by several pieces of evidence. First, during the Hart investigation, all of the split spoon samples taken in the till were dry. Secondly, the water level rose above the bedrock-till interface in every test boring except TB-8. In TB-8, drill water was lost down the hole when bedrock was encountered, and during the water level measurements MW-8 was consistently dry. The fact that the water level rose above the till-bedrock interface indicates the till has such a low permeability that there is almost no hydraulic connection between the two units. Furthermore, the low permeability of the till retards the movement of any significant quantity of water in the till itself.

Hart has provided contours from the monitoring wells of groundwater upwelling into the base of the glacial till, specifically on the General Switch property (Figure 4 of the 1984 Hart report). Small changes were observed in the water level measurements taken by Hart during the study period. With the exception of the measurement in MW-7 on the afternoon of September 14, 1984, these levels reflect natural fluctuations in the water levels due to rainfall, evaporation or changes in humidity. An approximate water level contour map was constructed from the data gathered on the morning of September 14, 1984

(Figure 3-14). The direction of flow is at a right angle to the contours and is indicated by the arrows on Figure 3-14. The flow directions probably reflect gradients in the hydrologic zone from the base of the till to the shallow bedrock. Since the till was unsaturated, it appears that water from the bedrock aquifer leaked into the monitoring wells and produced the observed water levels. The general lateral direction of groundwater flow in the till was from northeast to southwest, Figure 3-14, which is in contrast to the groundwater flow direction in the shale that was influenced in 1983-84 by the overpumping of the groundwater reserves on Highland Avenue.

Austin Glen Grit and Shale and the Shale Aquifer

In all of the eight soil borings drilled in the Fred C. Hart study, at least 5 feet of rock was drilled or several feet of rock was cored to confirm the bedrock surface. Rock cores were taken from TB-1, TB-6 and TB-8 to allow a visual inspection of the rock type and degree of weathering and fracturing in the rock. All three rock cores were taken with a 5-foot-long, 1½-inch-diameter core barrel supplied by Kendrick Drilling Co.

While bedrock in general slopes down to the south and west (Figures 3-7 and 3-9). There are several exposures of the glacial soils and underlying shale to be found near General Switch. The approximate elevation of bedrock is presented in Figure 3-15. A massive sandstone and shale is found to outcrop at the surface on the northern end of Watkins Avenue and near Lubricants, Inc. on Industrial Place, 450 feet southeast of the General Switch building. In these outcrops the degree of fracturing of the bedrock is visible along with the regional fracture pattern that has a significant influence upon the available avenues of groundwater flow and site hydrogeology.

The primary aquifer is found beneath the till in the Austin Glen Series sandstone and shale. This is a semiconfined bedrock aquifer in that the bedrock is covered with 25 feet of dense glacial till under General Switch and water levels in wells cased into the shale are observed to have risen to elevations feet into the glacial till. For instance, the water levels were noted in December 1983 and January 1984 in the General Switch well at or about 623 feet MSL, 12 feet below ground and 13 feet into the till. However, in the pump tests presented in Section 4 some leakage from the base of the glacial till is indicated. Following weathering and erosion of the overlying soil and rock, there has been a pressure release in the Austin Glen Series and fissures in the rock have opened as the overburden (the amount of rock above) has been reduced. In addition, earth movements have caused faults to develop in the sandstone and shale formation. These fault lines observed in the outcrops cut across all the regional structures of bedding planes and fissures and these fractures have a major influence on the flow of groundwater in the confined aquifer. Thus, in the sandstone and shale, the groundwater is not found between the mineral grains but is found in the secondary fissures and fractures cutting through the rock. These secondary fissures and fractures influence the abundance and direction of flow of the groundwater under the motive force of the difference in potentiometric head from one point to another. Groundwater will pass more slowly through rock with tight joints. Permeability and well yields in the Austin Glen Series can vary greatly within a short distance. This is determined in part by the degree of fracturing and openness of the joints and also by the interconnection of fractures.

During drilling of MW-14, adjacent to well W-33 (Contel), the majority of the water was encountered at the top of the bedrock. The top 2 feet of bedrock at 64± feet depth is fractured and broken.

3.3 WALLKILL WELL DATA

A survey of wells within ¼ mile of the site was completed by the Technical Assistance Team contractor to USEPA from October 1983 to February 1984. The data presented in a tabular form were updated with marginal notes in September 1989. (See Appendix 3, Wallkill Well Search Data Table.) During this investigation the table was updated and used to confirm the number and location of wells to be monitored during the pump test.

In 1983 when the wells along Highland Avenue were discovered, most of the residences along Highland Avenue were supplied from their own wells. Only the Perez (338 Highland Avenue) and Roselli (334 Highland Avenue) residences adjacent to General Switch were supplied through a 1-inch-diameter line from General Switch. A 1-inch supply line running from south to north from Middletown supplied residences along the south end of Watkins Avenue.

A temporary water line was constructed in the winter of 1983-1984 to supply municipal water to the residences with contaminated wells along Highland Avenue. This water line was subsequently replaced in 1985 by a permanent water line from Middletown. This area was annexed by the Township of Wallkill in 1987.

In October 1991, the Office of the Engineer of Wallkill provided an updated map of those residences served by the Township of Wallkill that was incorporated into Figure 3-16. At that time, the Township of Wallkill supplied drinking water to the majority of residences in the Annex except for residences on the 1-inch supply line at the south end of Watkins Avenue supplied from Middletown. Industries along Industrial Place were supplied with water from Middletown. The connection of individual residences along Highland Avenue to Wallkill water supply was reported in the Progress Reports submitted to the USEPA in 1990-1991.

Community Wells

Well W-30 (Parella) has been redeveloped and piping was laid to carry groundwater across to the air stripper on the General Switch property. Well W-31 (Electra Manufacturing) is now supplied with electricity and is capable of pumping at approximately 4 gpm. Wells W-18 (Ruppert) and W-17 (Barry) are able to be pumped using a generator for electric supply. Well W-1 (Perez) can be pumped and is fitted with an outside faucet. Well W-8 (Osbourne) is capable of being pumped and is fitted with an outside switch.

In March 1991, the renovations of the Liska well and W-33 (Contel, formerly Wallace Oil) wells were completed. The Lobb well has been cemented up. Well W-8 (Osbourne) is 50 feet from the Lobb well and can serve in its stead. The Liska well was filled with mud and rock. Well W-33 (Contel) was sampled and pump tested instead of the Liska well. Well W-16 (Lewis) was buried and will require excavation and the addition of casing to bring the wellhead to ground surface. Well W-30 (Parella) was uncovered and the casing was extended to ground surface along with well W-1 (Perez).

In September 1991, three wells on Highland Avenue were connected to the City water supply at the owners' request. The residences are W-13 (Wood, previously Ogden, 319 Highland Avenue), W-12 (Seeley, 321 Highland Avenue) and W-11 (Gilbert, 323 Highland Avenue), as shown on Figure 3-16. All occupied residences on Highland Avenue adjacent to General Switch between No. 338 and No. 304 are now supplied with municipal water supply. Figure 3-16 indicates the information that is currently available.

The pumps from seven wells -- W-30 (Parella), W-32 (Stout), W-8 (Osbourne), W-18 (Ruppert), W-17 (Barry), W-33 (Contel) and W-31 (Electra Manufacturing) -- were removed prior to bladder pump sampling. With the permission of USEPA and according to the agreements with the homeowners, these pumps will be replaced in the summer of 1993. Of the seven wells, W-8 (Osbourne), W-18 (Ruppert) and W-17 (Barry) still use their wells for watering their lawn and washing their cars. A memo will be submitted to USEPA requesting its policy with respect to these wells that are located inside the lateral extent of the plume. It is not anticipated that the homeowners would object to a moratorium on use of these wells inside the plume.

In general, since 1983, there has been a concerted effort to provide municipal water supply to the residents of Washington Heights. As of October 1992, the following residents still used their bedrock wells for drinking water supply:

Mould
Holmes
Pitt
Ernest
Cornelius (W-7)

The following residents still use their bedrock wells for watering their gardens:

Stout (W-32)
Gilbert (W-11)
Ogden (Wood) (W-13)
Perez (W-1)
Knapp (W-14)
Van Pelt (W-15)
Radivoy
Rasmussen (W-19)
Robaina (W-26)
Sleiter (Petrizzio)
Prior King Press
(factory water supply)
Wand (W-22)

Some of the residential wells were not operable, or had been destroyed. The following residential wells have been abandoned:

Roselli
Courteau
Crooks
Fiore
Lobb
Lewis (W-16)
Liska
Eckerson
Winner
Foote
Cosmo Optics
Jehovah's Witness
Liborio
Janiak

The following wells were dry:

MW-8, MW-5, MW-11

Table 3-2 shows the status of wells.

3.4 ROCK CORE ANALYSIS

3.4.1 Introduction

Rock cores were obtained in the bottom of selected soil borings and bedrock wells to confirm the depth to bedrock and obtain additional information regarding the bedrock. Rock coring was also performed adjacent to select residential wells and hotspots to determine the degree of fracturing in the bedrock.

Rock cores were obtained from bedrock wells MW-202, MW-203, MW-207, MW-12/soil boring SB-15, MW-14/soil boring SB-18, MW-15/soil boring SB-16, soil boring SB-1, soil boring SB-5 and soil boring SB-11 from June 22 to July 21, 1992, except for MW-15/soil boring SB-16, which was cored December 12, 1992.

The 2½-inch-diameter rock cores were collected using a 10-foot-long core barrel with NX (wet rotary) gauge bits.

Each core run was logged in the field for core recovery, which is expressed as a percentage of the length of core recovered to the length of the total core run. Rock Quality Designation (RQD) was also calculated for each core run. RQD, expressed as a percentage, is the ratio of the cumulative lengths of core pieces that are 4 inches or more in length to the run length. RQD, which does not account for breaks that occur during coring, provides a relative means of characterizing overall rock quality with higher percentages indicating more competent rock mass. Breaks caused by drilling or handling were identified by fresh clean surfaces, sharp edges, fitting tightly together.

For the purpose of this site investigation, the most important observations obtained from the rock cores are the frequency and type of fracturing. The location of each fracture was recorded on a core log to be able to fully evaluate the extent of fracturing. The type of fracture (bedding plane separation, shear, cleavage), fracture spacing, roughness, planarity, infilling/staining material, and angle of dip were recorded. In the event that the fracturing was too extensive, the location of the zone was identified and labeled as a highly fractured zone.

MW-202

Deep bedrock monitoring well MW-202, located approximately 80 feet southeast of W-30 (Parella) residential well, was cored from 41 to 100 feet below ground surface.

From 41 to 51 feet below ground surface, the recovery was 99% and the RQD is 68%. There appear to be two fracture zones: from 41 to 46 feet and from 49 to 50 feet below ground surface. Calcite was observed in some of the fractures.

From 51 to 61 feet below ground surface, the recovery was 100% and the RQD is 76%. There appear to be two fracture zones: from 53 to 54 feet and from 57 to 58.8 feet below ground surface. Calcite was observed in some of the fractures.

From 61 to 71 feet below ground surface, the recovery was 100% and the RQD is 67%. There appear to be two fracture zones: from 61 to 66 feet and from 68 to 69.6 feet below ground surface. Calcite was observed in some of the fractures.

From 71 to 81 feet below ground surface, the recovery was 100% and the RQD is 87%. There appear to be two fracture zones: from 77.5 to 78.4 feet and from 80 to 80.7 feet below ground surface. Calcite was observed in a few of the fractures.

From 81 to 91 feet below ground surface, the recovery was 89% and the RQD is 84%. The rock appears to be more competent with fewer fractures and no fracture zones. Calcite infilling was observed in some of the fractures.

From 91 to 100 feet below ground surface, the recovery was 86% and the RQD is 72%. There appears to be a fracture zone 5 feet in length from 95 to 100 feet below ground surface. Calcite was observed in a few of the fractures.

Overall, the rock quality was good from a depth of 51 to 61 feet and from a depth of 71 to 91 feet, as indicated by the RQD values. The frequency and occurrence of fracture zones decrease with increasing depth and the rock is generally more competent. Some of the fractures have calcite infilling, which indicates that calcium carbonate-rich groundwater has been percolating through some of these fracture zones.

MW-203

Deep bedrock monitoring well MW-203, located off the southeast edge of the General Switch parking lot adjacent to wells MW-16 and MW-3, was cored from 9.7 to 100 feet below ground surface.

From 9.7 to 13.7 feet below grade, the recovery was 89.6% and the RQD is 24.8%. There are 3 bedding plane separations, 3 identifiable fractures with slickensides, and 5 joints. Nearly all of the fractures exhibit limonite staining, with no calcite infilling. The core is highly fractured between 10.5 and 11 feet. This is probably mechanical breakage from drilling and coring operations.

From 13.7 to 7.7 feet below grade, the recovery was 93.3% and the RQD is 68.5%. There are 2 bedding plane separations and 2 joints, all containing minor calcite infilling.

From 17.7 to 20.2 feet below grade, the recovery was 97.1% and the RQD is 96.7%. There are 2 bedding plane separations and 6 joints. Surfaces in three of the joints have a calcite coating, and all of the fractures have minor limonite stains.

From 20.2 to 24.2 feet below grade, the recovery was 91.7% and the RQD is 85.8%. There are 3 bedding plane separations, 4 shear fractures, and one joint. Two of the fractures have calcite infilling and two have limonite stains or coating.

From 24.2 to 34.2 feet below grade, the recovery was 100% and the RQD is 93.5%. There are 10 bedding plane separations (two occurring at erosional surfaces between underlying shale and overlying sandstone) and 10 shear fractures. Thirteen of the fractures have calcite infilling and four exhibit slickensides.

From 34.2 to 43.9 feet below grade, the recovery was 100% and the RQD is 97.4%. There are 13 bedding plane separations and 10 joints. All but three of the fractures contain calcite infilling or coatings, and more than half of these are sealed. Four of the bedding plane separations exhibit slickensides.

From 43.9 to 53.9 feet below grade, the recovery was 100% and the RQD is 91.5%. There are 7 bedding plane separations and 5 joints. Ten of the fractures have minor calcite infilling. Four of the bedding plane separations have slickensides.

From 53.9 to 63.3 feet below grade, the recovery was 100% and the RQD is 94.3%. There are 10 bedding plane separations, 8 shear fractures, and 6 joints. All of the bedding plane separations and half of the other fractures contain calcite infillings. Most of the fractures are sealed. Three fractures exhibit slickensides. Multiple fractures occur between 60.4 and 62.4 feet below grade.

From 63.3 to 73.4 feet below grade, the recovery was 100% and the RQD is 92.6%. There are 7 bedding plane separations, 6 shear fractures, and 14 joints. Over half of the fractures are sealed. Most of the fractures have calcite infilling; vuggy calcite fills a shear fracture at 70.3 feet. Three calcite infillings also contain trace amounts of pyrite. Multiple fractures occur from 67.4 to 69.4 feet and from 70.4 to 71.7 feet.

From 73.4 to 83.4 feet below grade, the recovery was 100% and the RQD is 94.8%. There are 2 bedding plane separations, 3 identifiable shear fractures, and 16 joints and minor joints. Nearly all of the joints are sealed with calcite infilling. Slickensides are visible on one bedding plane separation and one shear. A probable shear with multiple fractures occurs at 76.5 feet.

From 83.4 to 93.6 feet below grade, the recovery was 100% and the RQD is 95.3%. There are 11 bedding plane separations, 9 shear fractures, and 12 joints and minor joints. More than half of the fractures are sealed. Three of the bedding plane separations have slickensides and two occur at erosional surfaces. Minor faulting accompanies the bedding separation at 89 feet. Multiple fractures occur from 91.8 to 93.6 feet, with calcite infilling from 0.3 to 1.5 inches thick.

From 93.6 to 100 feet below grade, the recovery was 100% and the RQD is 93.6%. There are 7 bedding plane separations, 7 shear fractures, and 8 joints, with multiple minor joints. Most of the fractures are sealed with calcite. Multiple fractures occur from 93.6 to 96.8 feet, with calcite infilling from 0.1 to 1.5 inches thick.

MW-207

Deep bedrock monitoring well MW-207, located approximately 200 feet southeast of W-30 (Parella) residential well, was cored from 28.5 to 100 feet below ground surface.

From 28.5 to 38.5 feet below ground surface, the recovery was 100% and RQD is 80.8%. There are 24 shear fractures and one highly fractured zone. Eight of the fractures have some degree of calcite infilling and one of the shears is slickensided.

From 38.5 to 48.5 feet below ground surface, the recovery was 100% and RQD is 86.9%. There are 18 shear fractures and one bedding plane separation. Three of the fractures have minor calcite infilling.

From 48.5 to 58.5 feet below ground surface, the recovery was 100% and RQD is 88.1%. There are 10 shear fractures and four bedding plane separations. Four of the fractures have minor calcite infilling.

From 58.5 to 68.5 feet below ground surface, the recovery was 100% and RQD is 96.6%. There are 8 shear fractures, one bedding plane separation and two highly fractured zones. Only the fracture zone has evidence of minor calcite infilling.

From 78.5 to 88.5 feet below ground surface, the recovery was 100% and RQD is 93.4%. There are 4 shear fractures, several of which have minor calcite infilling and slickensides.

From 88.5 to 97.5 feet below ground surface, the recovery was 100% and RQD is 95.2%. There 7 shear fractures, several of which have minor calcite infilling and slickensides.

From 97.5 to 100 feet below ground surface, the recovery was 100% and RQD is 100%. There is one shear fracture, which has no infilling.

MW-12/Soil Boring SB-15

Soil boring SB-15, which was converted into shallow bedrock monitoring well MW-12, is located adjacent to well W-30 (Parella) at 320 Highland Avenue. This boring was cored from 32.5 to 57.5 feet below ground surface. The two 10-foot and one 5-foot core runs had 99.2%, 99.2% and 98.3% recoveries. The RQDs of the three runs were 78.2%, 98.5% and 92%, which indicates that the rock quality is good to excellent.

For the 32.5 to 42.5 foot deep core run, there were 29 fractures, primarily resulting from shear with 4 bedding plane separations, and 3 highly fractured shear zones. For the 42.5 to 52.5 foot deep core run, there were 10 fractures resulting from shear. For the 52.5 to 57.5 feet deep core run, there were 5 fractures resulting from shear and one highly fractured shear zone.

For the total cored length there was some iron staining, which indicates that water is flowing through at least some of the fractures. The frequency of fractures decreased below a depth of 42 feet, indicating that the bedrock in this area may be competent at a relatively shallow depth.

MW-14/Soil Boring SB-18

Soil boring SB-18, which was converted into shallow bedrock monitoring well MW-14, is located adjacent to well W-33 (Contel) at 306-314 Highland Avenue. This boring was cored from 66.5 to 76.5 feet below ground surface and the core run had 100% recovery. Its RQD was 82%, which indicates that the rock quality is good. Over its 10-foot length there are a total of 20 fractures, primarily resulting from shear with 2 bedding plane separations. The frequency of fractures decreased toward the bottom of the hole, indicating that the bedrock in this area may be competent at a relatively shallow depth.

MW-15/Soil Boring SB-16

Soil boring SB-16, which was converted into shallow bedrock monitoring well MW-15, is located adjacent to well W-17 (Barry) at 309 Highland Avenue. This boring was cored from 50 to 60 feet below ground surface. The 10-foot core, which consists of three runs, had 82% recovery. The RQD of the core is 35.5%, which indicates that the rock quality is poor.

The 8.2-foot recovered core has one highly fractured zone that is approximately 2.8 feet in length. The lower 5 feet of the core is more competent than the top half; however, there are 23 fractures. Some of the fractures have calcite infilling or iron staining, which indicates that calcium carbonate and iron-rich groundwater has been percolating through some of these fracture zones. A high degree of fracturing is expected for the top of bedrock, which is not usually competent rock.

Soil Boring SB-1

Soil boring SB-1, located off the southeast edge of the General Switch parking lot adjacent to wells MW-16, MW-3 and MW-203, was cored from 12 to 22 feet below ground surface. The core had 80% recovery and an RQD of 5%, which is characterized as very poor quality. The 8 foot recovered core is characterized by highly fractured zones. Some of the fractures have calcite infilling or iron staining, which indicates that calcium carbonate and iron-rich groundwater has been percolating through some of these fracture zones. A high degree of fracturing is expected for the top of bedrock, which is not usually competent rock.

Soil Boring SB-5

Soil boring SB-5, which is located on the east corner of the Electra Manufacturing Company property (328-332 Highland Avenue), was cored from 21 to 31 feet below ground surface. The core had 100% recovery and an RQD of 86.5%. The 29 fractures occurred primarily in the upper half of the core, with the frequency decreasing at the bottom of the core, which indicates that the bedrock in this area may be competent at a relatively shallow depth.

Soil Boring SB-11

Soil boring SB-11, which is located under the TP-D hot spot by the south corner of the General Switch building, was cored from 24.4 to 34.4 feet below ground surface. The core had 100% recovery and an RQD of 27%, which is poor quality. The 10-foot core is characterized by highly fractured zones. Some of the fractures have calcite infilling or iron staining, which indicates that calcium carbonate and iron-rich groundwater has been percolating through some of these fracture zones. A high degree of fracturing is expected toward the top of bedrock, which is not usually competent rock.

3.4.2 Preliminary Conclusions

Evaluation of the rock cores indicates that the shale bedrock beneath the site is highly fractured. The fractures are more frequent with increasing depth. This is to be expected, as the overburden stress increases with depth; thus, the rock is less likely to develop fractures.

There are apparently water-bearing fractures, as evidenced by smooth rock surfaces at many of the fractures and numerous fractures that are filled with calcite crystals or iron staining. The great number of water-bearing fractures in the rock cores indicates that there may not be preferential transport through one set of fractures or fractures at only certain depths. As a result of the uniformity of water-bearing fractures, it may not be possible to isolate specific zones of contaminant transport.

3.5 BOREHOLE LOGGING

3.5.1 Introduction

Borehole logging was conducted on selected bedrock monitoring wells, residential wells and shallow bedrock monitoring wells in the study area in order to obtain additional information regarding subsurface conditions. The borehole logging was specifically performed to determine the location and frequency of possible fractures in the bedrock. Each well or boring selected was logged for natural gamma, conductivity, resistivity and

3-point caliper measurements. Bedrock monitoring well MW-204 was additionally logged for thermal variations.

Wells MW-2-2, MW-203, MW-204, MW-207, W-8 (Osbourne), W-17 (Barry), W-30 (Parella), W-31 (Electra), W-32 (Stout), W-33 (Contel) and MW-12, and soil borings SB-1 and SB-11 were logged by Delta Geophysical Services, Inc. on August 3-4, 1992. MW-202, which was installed on September 5, 1992, was logged on November 7, 1992.

The geophysical logs are contained in Appendix 2.

3.5.2 Logging Methods

Caliper logging measures the diameter of the borehole wall, and is useful in determining roughness, indentations or irregularities along the borehole surface. Large irregularities, which may be indicative of fracture zones, can be identified by deflections measured with the caliper log. When reviewing the caliper logs, it should be noted that there is horizontal exaggeration in that the horizontal deflections appear larger than they actually are relative to the depth. The exaggeration is due to unequal scales. One unit in the horizontal direction equals 0.2-0.4 inches, while one unit in the vertical direction equals 2 feet.

Conductivity logging, which is also referred to as spontaneous potential logging, measures the formation's ability to conduct electrical current. Spontaneous potentials are naturally occurring electric potentials that result from chemical and physical changes at the contacts between differing types of geologic units. Electric potentials can also be affected by water moving into or out of a borehole, such is the case at fractures or highly permeable zones. In addition, a fluid's conductivity changes with varying concentrations of dissolved ions, such as saline water or solvent contamination, and therefore fracture zones that carry contamination can be identified through variations in conductivity. Thus, conductivity logging was performed to measure zones of varied conductivity to determine potential water-bearing fracture zones.

Resistivity logging measures the natural electrical resistivity of the formation. Electrical current is forced between the electrodes placed in the borehole to measure current loss. Variations in resistivity are caused by differences in the formation's mineralogy and water content. Dry formations are poor electrical conductors and therefore show high resistivities. Resistivity of saturated formations also decreases with increasing dissolved ions and, inversely, increases with decreasing dissolved ions. Fine-grained units, such as silts and clays, are less resistive than coarse-grained materials like sands or gravel.

Natural gamma logging measures the naturally occurring radiation in the formation. Since different types formations have natural variations in radiation, it is possible to distinguish differing formations based upon the varying levels of radiation. For example, clays and shales have higher concentrations of radioactive elements than sands and gravel. Calcium carbonate (calcite) can also emit high concentrations of radiation due to radioactive impurities; this is important in that many of the fractures in the aquifer beneath the site contain calcite infilling (see Section 3.4, Rock Coring Analysis). Gamma radiation can therefore be useful in correlating lithology, permeability and fracture occurrence.

Temperature logging measures the thermal gradient of the borehole. A temperature probe is slowly lowered down a borehole to measure change in temperature with increasing depth. The thermal gradient can be useful in evaluating vertical flow in the borehole. Higher vertical flow rates result in lower thermal gradients, and oppositely lower vertical flow rates result in higher thermal gradients.

Since rock cores were obtained from several of the wells or borings, some of the geophysical log interpretations were checked against the rock cores.

3.5.3 Logged Wells

MW-202

Well MW-202, which was logged soon after its installation, was logged from the ground surface to the base of the well at a depth of 100 feet below ground surface. The caliper log showed little variation from the bottom of casing, set at a depth of 40 feet, to the bottom of the well at 100 feet. This is probably due to the fact that this well was recently drilled and therefore the borehole walls have not deteriorated appreciably. From the gamma, resistivity and conductivity logs, it appears that there are zones of variation (i.e., increased or decreased measurements) at depths of approximately 43 feet, 52 feet, 64 feet and 80-86 feet. These variations consist of alternating peaks of high resistivity, low gamma and low conductivity and peaks of low resistivity, high gamma and high conductivity. These anomalous readings may be indicative of fractures or possibly variations in the lithology, such as alternating layers of sands and shales.

The rock cores obtained from this well were inspected to confirm the geophysical interpretations. All of the high resistivity peaks, with the exception of the peak at 52 feet, were due to sand layers that ranged in thickness from several inches to 2 feet. The deflection at 52 feet was due to a fracture that was filled in with approximately 2 inches of calcite. The very low conductivity peaks were inspected and found to be due to fractures. The very small, closely spaced conductivity deflections between 88 and 98 feet are due to varied layers of silts and sands.

MW-203

Well MW-203, which was logged soon after its installation, was logged from the surface to the bottom, which is 98 feet below ground surface. Since this well was recently installed, the caliper log of this well indicated that the borehole wall is competent. The caliper log showed little variation from the bottom of casing at a depth of 9 feet to the bottom of the well at 98 feet, with the exception of a deflection at approximately 17 feet below grade. This offset deflection indicates that the borehole diameter decreases slightly. At this point, the resistivity is very low and the conductivity is very low. These two facts together indicate there may be a change in lithology at this point, which is significant in that water may be transmitted to the well through the interface of the two layers.

From the gamma, resistivity and conductivity logs, it appears that there are zones of variation at depths of 28 feet, 32 feet, 58-66 feet, 76-84 and 90-100 feet. At 28 feet, there is a high conductivity reading opposite low gamma and high resistivity measurements. At 32 feet, there is a low conductivity reading opposite low gamma and high resistivity measurements.

At 58-66, 76-84 and 90-100 feet, there are very high resistivity and very low gamma measurements. From these data, it appears that these zones contain water-bearing sand layers interbedded with shale.

The rock cores obtained from this well were inspected to confirm the geophysical interpretations. Deflection in the caliper log at 17.5 feet appears to be the result of bedding plane separations. Trace amounts of calcite infilling and limonite staining on the separation surfaces suggest water transmission through these fractures at some time. The very high conductivity peak at this depth may indicate increased contaminant concentrations in the water.

Low gamma and high resistivity peaks at 28 and 32 feet correlate with lithologic changes in the core. The change from shale to sandstone at 28 feet is accompanied by shearing and bedding plane separation. This may explain the low conductivity peak at this depth. A similar change occurs at 32 feet, with fracturing between 32.4 and 32.8 feet.

Relatively continuous sandstone beds occur from 62.5 to 66 feet and from 76.6 to 84.8 feet. The interval from 90 to 100 feet is predominantly sandstone, with thin shale layers interbedded.

Fluctuations in the conductivity log at this depth correspond to observed fracture zones in the core.

MW-204

Well MW-204 was logged from near the ground surface to the bottom of the well at a depth of 115 feet. The steel casing is installed to a depth of 15 feet below ground surface. Although this well was newly installed, there are several fractures that are identifiable on the caliper log. There are several small caliper deflections at 42-44 feet, 60-62 feet and 70-73 feet, and one significant deflection at 91.5 feet below ground surface. At these locations, high conductivity and gamma measurements and low resistivity readings were recorded. This data indicates that these are potentially water-bearing fracture zones.

In addition, MW-204 was logged for thermal variations. The upper zone of the well, near the surface was approximately 11° C, which rapidly decreased to 10.5° C at the bottom of the casing. The temperature remained slightly less than 10.5° C until approximately 40 feet below grade, where the temperature increased to 10.6° C. At this point, the temperature increased and stabilized at approximately 10.7° C. This thermal stabilization could indicate that the water table was encountered. Within the water column, the temperature remained fairly constant with only a slight increase as the thermal probe was lowered to the bottom of the well. No variations were identified at the locations of the fractures. Since the well water is at equilibrium, i.e., no pumping or external interferences, the temperature should be fairly constant.

MW-207

Well MW-207, which was logged soon after its installation, was logged from the surface to the bottom, which is 97 feet below ground surface. The caliper log showed little variation from the bottom of casing at a depth of 27 feet to the bottom of the well at 97 feet. At 36 feet and 66-69 feet there are high conductivity and gamma measurements, which may be indicative of potentially water bearing shale fracture zones. High resistivity and low gamma readings were recorded at depths of 34 feet, 44 feet, 46 feet, 49 feet, 90 feet, 92 feet, 94 feet, and 97 feet (no gamma readings after 94 feet). This data indicates that these are sand zones that contain minor or little amounts of clays. At 64 feet deep, there are high conductivity, high resistivity and low gamma readings which could be indicative a water-bearing sand zone.

The rock cores obtained from this well were inspected to confirm the geophysical interpretations from 70 to 100 feet. All of the high resistivity peaks from 76 to 100 were due to sand layers that ranged in thickness from 6 inches to 1 foot. The very low conductivity peaks were inspected and found to be due to fractures. The very small, closely spaced conductivity deflections between 70 and 86 feet are due to varied layers of silts and sands.

W-8 (Osbourne Well)

Well W-8 (Osbourne), which is cased to 23 feet below grade, is approximately 216 feet deep. W-8 is a relatively old residential well, and the caliper log indicates that the borehole is rough and deteriorated. Caliper deflections were noted for the entire length of logged hole; however, the most significant deflections were noted at 23-25 feet, 35 feet, and 41-44 feet.

From 27 to 216 feet, the conductivity data, in conjunction with the other log data, indicate that there are highly conductive zones at 41 feet, 45 feet, 48 feet, and 187 feet. At 41 feet there is a high conductivity reading in addition to a significant caliper deflection, and high gamma and low resistivity readings. These data indicate that this may be a water-bearing fracture in the shale. The same types of readings, although not as pronounced, occur at depths of 45 and 48 feet. These two zones may also be fractured shale bedrock that are transmitting water to the well. The greatest conductivity measurement was obtained at a depth of 187 feet. At this location there is a very high conductivity reading in addition to a caliper deflection, and high gamma and low resistivity readings. These data indicate that this may be a fracture bearing a highly conductive pore fluid, such as groundwater that contains a high concentration of ions.

The 40-foot-thick zone from 147 to 187 feet has several slightly elevated conductivity readings in conjunction with very high resistivity and very low gamma measurements. From these data, it appears that this zone contains water-bearing sand layers possibly interbedded with shale. A very high conductivity reading occurs at the base of this 40-foot-thick high resistivity zone, and could possibly indicate that water is being transmitted in large quantities at the interface, possibly a fracture, of the base of the sands and the top of a less permeable shale zone.

W-17 (Barry Well)

Well W-17 (Barry well), which is cased to 42 feet below grade, is approximately 203 feet deep. W-17 (Barry) is a relatively old residential well, and the caliper log indicates that the borehole is rough and deteriorated. Caliper deflections were noted for the entire length of logged hole; however, the most significant deflections were noted at 49-52 feet, 70 feet, and 104-106 feet.

The caliper deflections at 52 feet and 70 feet also had high conductivity, low resistivity and low gamma measurements, which indicates that these could be water-bearing fracture zones. At 81 feet, there is a high conductivity reading, a high gamma measurement and a slightly decreased resistivity reading. At 104-106 feet, there is a fracture identified on the caliper log; however, the conductivity reading is not elevated and therefore this location may not be a significant water-bearing zone.

The approximately 40-foot-thick zone from 140 to 176 feet has several slightly elevated conductivity readings in conjunction with very high resistivity and very low gamma measurements. From these data, it appears that this zone contains water-bearing sand layers possibly interbedded with shale. A very high conductivity reading occurs at the base of this 40-foot-thick high resistivity zone, and could possibly indicate that water is being transmitted in large quantities at the interface of the base of the sands and the top of a less permeable shale zone.

W-30 (Parella Well)

Well W-30 (Parella) is cased to a depth of 34 feet, and is drilled to a depth of 128 feet. The caliper log shows that the open borehole is rough and deteriorated, as would be expected for a relatively old well. The caliper log shows that there are several zones of pronounced deflections; these deflections occur at 34-41 feet, 46 feet and 74-76 feet.

At the 34-41 feet and 46 feet caliper deflections, there are relatively low resistivity and slightly high conductivity readings. The two closely spaced caliper deflections at 74-76 feet had slightly elevated resistivity and slightly high conductivity readings. These zones may be composed of water-bearing shale layers. At 72-76 feet, 84-96 feet and 114-121 feet there are zones of high resistivity, low gamma and average to slightly elevated conductivity readings. These zones may be sand layers that transmit minor amounts of water.

W-31 (Electra Well)

Well W-31 (Electra well) is cased to a depth of 22 feet and has a total depth of 120 feet below ground surface. The entire open borehole was logged; however, the resistivity and conductivity logs indicate that there is interference from a metallic object situated from approximately 90 or 97 feet deep to the bottom of the well.

The caliper log shows that the borehole surface is rough and deteriorated, which is probably due to the age of the well. Several deflections have been noted that indicate that there may be fractures in the surface of the borehole. The most pronounced of these caliper deflections were noted at depths of 38 feet and 55 feet.

At 38 feet there were no significant deflections in the resistivity, conductivity or gamma logs. At 55 feet there was a minor decrease in the resistivity and a slight increase in the conductivity reading, which indicates that this may be a water-bearing fracture.

W-32 (Stout Well)

Well W-32 (Stout), which is cased to 50 feet below grade, is approximately 127 feet deep. W-32 is a relatively old residential well, and the caliper log indicates that the borehole is rough and deteriorated. Caliper deflections were noted for the entire length of logged hole, however the most significant deflections were noted at 53 feet and 55-57 feet. The deflection at 53 feet protrudes out of the borehole wall and acts as an obstruction during collection of manual water level measurements. Protrusions often encountered in boreholes can be due to pieces of bedrock jarred loose during drill tool withdrawal or bent ends of steel well casing. Since the resistivity log measurements remained fairly constant while the resistivity probe was lowered down the cased section of the hole to the base of the protrusion, this indicates that the protrusion may be similar to the casing, and not bedrock material. The deflection at 55-57 feet may be a significant fracture; however; due to the lack of conductivity and resistivity data at this location, it is difficult to fully evaluate the caliper data.

From 60 to 127 feet, the conductivity data, in conjunction with the other log data, indicates that there may be two noteworthy zones. At 62 feet there is a very high conductivity reading in addition to a minor caliper deflection, and low gamma and resistivity readings. The same type of readings, although not as pronounced, occur at a depth of 81 feet. These two areas may be zones of fractured shale bedrock that are transmitting water to the well.

W-33 (Contel Well)

Well W-33 (Contel), which is cased to 67 feet below grade, is approximately 192 feet deep. The pump and associated piping were apparently dropped to the bottom of the well by a plumbing contractor prior to this site investigation. The piping begins at a depth of 106 feet and extends to the bottom. Since the steel well casing and metal piping interfere with the resistivity and conductivity measurements, these readings were collected only for the interval between 67 and 106 feet.

Since well W-33 is a relatively old residential well, the caliper log indicates that the borehole is rough and deteriorated. Caliper deflections were noted for the entire length of logged hole; however, the most significant deflections were noted at 69-75 feet, 136-140 feet, 145-147 feet, and at 161 feet. These deflections could be indicative of fracture zones that deteriorated quicker than the more consolidated bedrock.

The most pronounced caliper deflection occurred at 75 feet. At this location, high conductivity, high resistivity and low gamma readings were recorded, which could be indicative of a water-bearing sand zone. Another significant deflection was noted at a depth of 161 feet; however, due to the lack of conductivity and resistivity data deeper than 106 feet, it is difficult to fully evaluate the logging data.

MW-12 (Shallow Bedrock Well)

Monitoring well MW-12, located immediately adjacent to well W-30 (Parella), is a shallow bedrock well. The steel casing is set to a depth of 32 feet and the total well depth is 58 feet. Since this well was recently installed, the caliper log of this well indicated that the borehole wall is competent. There is, however, an offset deflection at a depth of 39 feet where the borehole diameter decreases slightly. This fact would not be significant in itself, but the resistivity log indicates that there is layer of high resistivity rock beginning at this same depth. These two facts together indicate there may be a change in lithology at this point, which is significant in that water may be transmitted to the well through the interface of the two layers.

In order to substantiate this conclusion, the geophysical logs from well W-30 (Parella) were compared with the logs from MW-12. In W-30 there is also an increase in resistivity at a depth of 40 feet. Above this high resistivity layer is a zone of several fractures, as evidenced by the caliper log. In order to determine if this set of fractures transmits appreciable amounts of water, the zone from 32-42 feet was packer tested. The results of the packer testing will be evaluated in a later submission.

Soil Boring SB-1

Soil boring SB-1, which was drilled adjacent to deep bedrock well MW-203 and shallow wells MW-3 and MW-16, was logged from the base of the casing to 22 feet below ground surface. The temporary steel casing, used to keep the borehole in the unconsolidated sediments open, extended to a depth of 12 feet and was removed prior to sealing of the boring.

There are two caliper deflections noted in the borehole. The first deflection is noted at a depth of 14 feet. At this depth, there is a high gamma reading and a low conductivity measurement (no resistivity data). This could be indicative of a fracture, but the low conductivity may mean that it does not transmit water. The second deflection is an offset at a depth of 18 feet where the borehole diameter decreases slightly. At the same depth, the conductivity decreases significantly and the resistivity log indicates that there is layer of high resistivity rock beginning at this depth. This indicates that there is a change in lithology at this point, possibly a shale zone overlying a sand zone with a fracture separating the two layers. This is significant in that water may be transmitted to the well through the fracture at the interface of the two layers.

Soil Boring SB-5

Soil boring SB-5 was drilled on the east corner of the Electra property (328-332 Highland Avenue) and is located between deep bedrock well W-31 and shallow well MW-17. SB-5 was logged from the base of the casing to 20 feet below ground surface. The temporary steel casing, used to keep the borehole in the unconsolidated sediments open, extended to a depth of 6 feet and was removed prior to sealing of the boring.

The caliper log indicates that the borehole wall is highly irregular. Since this boring was drilled prior to geophysical logging, it is unlikely that the borehole deteriorated with time. Most likely the irregularities are due to the top of bedrock being highly fractured, which commonly occurs with a fissile shale.

Comparing the conductivity and caliper logs, it appears that there may be fracture zones at 8 feet and 14 feet below ground surface. At both of these points, there are significant caliper deflections and low conductivity readings, which may be indicative of water-bearing fracture zones that separate two lithologies.

Soil Boring SB-11

Soil boring SB-11, which was drilled adjacent to shallow wells MW-16 and VES-2, was logged from the ground surface to a depth of 35 feet. The temporary steel casing extended from the ground surface to 23 feet deep.

The caliper log indicates that the borehole wall is rough, but there are no notable deflections which could be indicative of fractures. At a depth of 24 feet there is a high resistivity reading and a low gamma measurement (no conductivity data), which could be indicative of a sand layer. The rock core from this depth was inspected and found to contain a 6-inch sand layer. There is also a high resistivity measurement at 33 feet, but since there are no gamma or conductivity readings and it is close to the bottom of the borehole, it is not possible to determine if the deflection is truly indicative of subsurface conditions.

At approximately this depth there is a fracture filled with a 3-inch thick layer of calcite that may account for the high resistivity reading.

3.5.4 Preliminary Conclusions

From the borehole logging it is possible to identify potential zones of fractures and lithology changes. In addition, it is possible to evaluate and correlate strata from areas of known lithology to areas that have not been logged. For example, there is a group of distinct sand layers that is evident in the geophysical logs of W-8 (Osbourne), W-17 (Barry), MW-203 and MW-204. By choosing one of the sand layers, for example the middle layer, then taking its depth from ground surface and subtracting that value from the ground surface elevation, the elevation of the sand layer can be obtained. Approximate elevations of the middle sand layer are 550 feet MSL for MW-204, 544 feet MSL for MW-203, 485 feet MSL for W-17 and 482 feet MSL for W-8. Although there are not enough points to accurately create a stratigraphic contour map, it is apparent that the sand layer slopes from the southeast (MW-204 and MW-203) to the northwest (W-17 and W-8). This is confirmed by published geologic research papers that indicate the bedding plane dip is to the northwest.

SECTION 4

CONTENTS

4.0 SITE HYDROGEOLOGY

The overall objective of the hydrogeologic investigation at the General Switch site was to determine the characteristics of the bedrock and unconsolidated aquifers beneath the site. The well completion data for all wells investigated is contained in Table 4-1.

Slug tests were performed on the shallow unconsolidated monitoring wells which were installed into the glacial till and fill material. The slug test results were used to determine hydraulic conductivity of the unconsolidated sediments. The hydraulic conductivity of the unconsolidated sediments was compared to the hydraulic conductivity values obtained for the bedrock aquifer to determine if there is hydrogeologic unconformity between the two aquifers.

Step-drawdown tests were performed on select deep bedrock residential wells and deep bedrock monitoring wells to determine the optimum yield of wells. The step tests were also used to evaluate drawdown and the degree of hydrogeologic connection between various observation wells.

Based on the findings of the step-drawdown tests, the optimum pumping rate and suitable observation wells were selected for the long term pump test on (W-30) the Parella well. Section VII(A) of the Consent Decree states that the primary objective of the long term pump test on the (W-30) Parella well is as follows:

> "The pump test shall be performed for the purpose of demonstrating that the (W-30) Parella well is satisfactory for interception (through pumping/capture) of the contaminant plume underlying or near the site."

The pump test data was used to determine aquifer characteristics, such as hydraulic conductivity and storativity. Characteristics such as hydraulic gradients, velocity and flow direction for the bedrock aquifer were also determined through site investigation. These aquifer parameters were evaluated to develop capture zone models for groundwater recovery from the (W-30) Parella well to demonstrate satisfactory interception of the contaminant plume.

4.1 <u>SLUG TESTS</u>

4.1.1 Introduction

In accordance with the approved Revised Sampling, Analysis and Monitoring Plan ("RSAMP") dated April 22, 1992, slug tests were performed on shallow unconsolidated monitoring wells at the General Switch site. The slug tests were conducted on August 10 and 11, 1992.

The slug tests were performed to determine the aquifer characteristics of the shallow overburden aquifer, which consists primarily of glacial till and in some areas, fill material. The aquifer characteristic of hydraulic conductivity for the overburden material at various areas of the site will be compared to determine if the aquifer characteristics are similar throughout the site or if there are significant differences.

This section sets forth the slug test setup and operation, the hydrogeologic results, calculations of aquifer characteristics, and interpretations of the findings. The results and conclusions obtained will be evaluated in conjunction with the other RSAMP study results in order to assess the overall site hydrogeology.

4.1.2 Aquifer Tests

The slug tests were performed to determine aquifer characteristics of the unconsolidated aquifer. Slug tests were performed on wells MW-1, MW-2, MW-3, MW-4, MW-5, MW-7, MW-8, MW-11, MW-16, MW-17, OB-3, OB-9 and VES-1. The thirteen (13) tests were conducted August 10-11, 1992.

Each slug test consisted of quickly removing a small volume of water from the well in order to measure the rise of the water level. For each test, the well was outfitted with a pressure transducer, connected to a data logger, to automatically measure and record water levels. Prior to each test, the probe was installed in the well and the water level was monitored for up to ten minutes in order to allow the water level to stabilize. Upon removal of a slug of water, the water level was monitored for approximately 1 to 1½ hours. The amount of time that each well was monitored was decided in the field based on the observed response. Those wells that recovered slowly were monitored longer, while those wells that recovered quickly were not monitored as long.

The slug test data for the thirteen (13) logged wells showing date, time, elapsed time, water level and drawdown are presented in Appendix 4-A.

4.1.3 Data Analysis

The Bouwer and Rice method was used to analyze the slug test data. The Bouwer and Rice method, which is applicable for wells partially or fully penetrating unconfined aquifers, was selected because the shallow wells that were tested are screened in the unconsolidated overburden deposits. The water table in these deposits is unconfined, in addition, some of these wells are not fully penetrating.

The Bouwer and Rice method was applied with the assumption that all wells were fully penetrating, that is, the saturated thickness of the aquifer is equivalent to the height of water in the well. For most of the unconsolidated wells at the site, the screen extends from the top of bedrock to above the water table, and thus are fully penetrating. A few wells are not screened to bedrock, however, and therefore are considered partially penetrating wells. Since the exact depth to bedrock is not known for these wells, the assumption was made that the height of the water column in the well was equivalent to the saturated thickness.

Using the AQTESOLV program the slug test drawdown data was plotted against time on a semi-logarithmic graph, with displacement (drawdown recovery) on the logarithmic scale. A straight line was fit through the plotted points and the value for hydraulic conductivity was calculated.

The plots of log displacement versus time for the thirteen slug tests are contained as Graphs 4-1 through 4-13. Most of the data plotted on straight lines, however some of the data, such as for MW-2, MW-11 and OB-3, did not have good correlation. The data for these wells fall within the range of values obtained for the other wells, therefore all values are considered valid.

Table 4-2 contains a summary of the hydraulic conductivity values obtained from the data analysis. The results indicate that hydraulic conductivity values range from 0.1069 x 10^{-4} feet per minute (MW-11) to 19.81 x 10^{-4} feet per minute (MW-3). The geometric mean is 0.8669 x 10^{-4} feet per minute. Since the range of values is not within the same order of magnitude, it is appropriate to calculate the mean hydraulic conductivity value instead of the average.

4.1.4 Conclusions and Recommendations

Slug tests were performed on the unconsolidated wells at the site in order to obtain hydraulic conductivity values for the water table aquifer. The Bouwer and Rice method was used to evaluate slug test data for the unconfined fill and glacial till aquifer.

The results indicate that hydraulic conductivity values range from 0.1069 x 10^{-4} feet per minute in MW-11 to 19.81 x 10^{-4} feet per minute in MW-3, with a geometric mean of 0.8669 x 10^{-4} feet per minute. The results indicate that there is variation in the hydraulic conductivity over the entire area of the unconsolidated wells, which indicates that there is not a consistent difference in hydraulic conductivity between the glacial deposits and the imported fill. The hydraulic conductivity values obtained for the glacial till and fill material are consistent with those values obtained for the bedrock aquifer, as discussed in Section 4.3 of this report.

4.2 STEP-DRAWDOWN TESTS

4.2.1 Introduction

In accordance with the approved Revised Sampling, Analysis and Monitoring Plan ("RSAMP") dated April 22, 1992 and the Revised Pump Test Plan, two phases of step-drawdown tests were performed at the General Switch site.

The first phase of step-drawdown tests were performed on seven residential wells between June 22 and July 22, 1992. The following wells were tested: W-30 (Parella well at 320 Highland Avenue), W-31 (Electra well at 328-332 Highland Avenue), W-33 (Contel well at 306-314 Highland Ave), W-17 (Barry well at 309 Highland Avenue), W-18 (Ruppert well at 307 Highland Avenue), W-8 (Osbourne well at 329 Highland Avenue) and W-1 (Perez well at 338 Highland Avenue).

The second phase of step-drawdown tests were performed on wells MW-202, MW-203 and MW-207. The step-drawdown test on MW-202 was conducted September 17, 1992, the step-drawdown test on MW-203 was conducted December 22, 1992, and the step-drawdown test on MW-207 was conducted September 25, 1992. A step-drawdown test was not required for MW-204, based on written approval from the USEPA. The data for the step-drawdown tests of MW-202 and MW-207 were unavailable, and therefore these tests had to be repeated. The step-drawdown test on MW-202 was conducted March 31, 1993, and the step-drawdown test on MW-207 was conducted April 1-2, 1993.

The step-drawdown tests were performed to determine the well characteristics such as optimum sustainable yield, specific capacity and well losses for each of the selected wells. Depending on the yield and condition of the well, each test lasted on the average from 4 to approximately 12 hours.

This report sets forth the step-drawdown test procedures, the hydrogeologic results, calculations of well characteristics, and interpretations of the findings. The results and conclusions obtained will be evaluated in conjunction with the other RSAMP study results in order to assess the overall site hydrogeology and characterization.

4.2.2 Groundwater Contours and Flow Directions

Water level data was obtained from select residential and monitoring wells at the study area prior to and during the step-drawdown tests. The water levels were converted to water elevations by subtracting the depth to water from the well casing elevations, which were previously surveyed by a licensed surveyor. The groundwater elevations for pre-pumping conditions (static) and for maximum drawdown conditions were plotted and contoured. It should be noted that for future tests, more wells will be manually monitored for static and drawdown conditions to obtain additional data, which will be useful in preparing more reliable contour maps.

For contouring purposes, the groundwater elevations for the deep bedrock monitoring wells and the residential wells were mapped separately from the shallow unconsolidated monitoring wells. The shallow bedrock wells were not contoured for two reasons. First, the open hole intervals of the shallow bedrock wells are in the top of bedrock so it would be inappropriate to include the elevations with either the deep bedrock wells or the shallow overburden monitoring wells. Second, for the step-drawdown test of MW-203, only two of the shallow bedrock wells were monitored (one of the monitored wells is MW-14, which may be anomalous - see Section 3.0 of the Pump Test Report - No. 3) and therefore it would be inappropriate to produce a contour map from two data points. Therefore, contour maps were produced only for the deep bedrock wells and the shallow overburden monitoring wells.

4.2.2.1 Drawdown Groundwater Flow - First Phase

Limited but measurable drawdown was observed in all selected observation wells during the first phase of step-tests, with one exception: during the step-test on well W-8 (Osbourne), there was no measurable drawdown on the selected observation wells. The lack of measurable drawdown in these wells is attributed in part to the quick dewatering of the well, and to the fact that the selected observation wells may not be hydraulically connected with the pumping well W-8 (329 Highland Avenue).

The response of the observation wells in terms of drawdown is summarized in Table 4-3. The cones of depression induced for each step-drawdown test are illustrated on Figures 4-1 through 4-6. The response from the hand monitored wells were not plotted on the figures due to minimal available data.

Referring to Table 4-3, the drawdown in the wells ranged from no response (0.00 feet) in the W-32 (Stout well) during the step-test of well W-31 (Electra) to 14.89 feet in well W-18 (Ruppert) during the step-test of well W-17 (Barry). The 15.18 foot drawdown observed in well W-19 (Rasmussen) midway into the step-test at well W-18 (Ruppert) may not be associated with pumping at well W-18. Rather, it is suspected that well W-19 (Rasmussen) may have been pumped by the owner during the well W-18 step-test.

Significant drawdown in the surrounding observation wells, as illustrated in the graphs of the pump tests for well W-30 (Parella) and W-33 (Contel) and as illustrated on Figures 4-4 and 4-6, indicates that these two wells have the most significant effects on wells located around and along Highland Avenue. It may also indicate that the wells are hydraulically interconnected through some major fractures.

4.2.2.2 Static Groundwater Flow - Second Phase

For the step drawdown test of MW-202, the water level data for the monitored wells is contained in Table 4-4. Figures 4-7 and 4-8 are the static water level contour maps for March 31, 1993 for the deep bedrock wells and the shallow overburden monitoring wells, respectively. As shown in both Maps 4-7 and 4-8, the direction of groundwater flow under static conditions is from north to south.

For March 31, 1993, the groundwater elevations in the deep bedrock aquifer (Figure 4-7) decrease from 645.06 feet mean sea level (MSL) at well W-1 (Perez) and 643.39 at well W-8 (Osbourne) to 616.83 feet MSL in well MW-204 and 617.75 feet MSL in well W-33 (Contel). The groundwater elevations in the shallow overburden aquifer (Map 4-8) decrease from 647.19 feet mean sea level (MSL) at well MW-8 to 608.37 feet MSL in well MW-9. The general trend of the groundwater table in both aquifers follows the slope of the hillside from north to south and towards the wetlands.

The water level data for the wells monitored during the step test of MW-203 is also contained in Table 4-4. Figures 4-13 and 4-14 are the static water level contour maps for December 22, 1992 for the deep bedrock wells and the shallow overburden monitoring wells, respectively.

On December 22, 1992, as shown in both Figures 4-13 and 4-14, the direction of groundwater flow under static conditions in the shallow aquifer and the bedrock aquifer is from north to south. The groundwater elevations in the deep bedrock aquifer (Figure 4-13) decrease from 629.78 feet mean sea level (MSL) at well W-30 to 615.46 feet MSL in well MW-204. The groundwater elevations in the shallow overburden aquifer (Figure 4-14) decrease from 628.65 feet MSL at well MW-2 to 615.38 feet MSL in well MW-4. The general trend of the groundwater table in both aquifers follows the slope of the hillside from north to south and toward the wetlands.

For the step drawdown test of MW-207 the water level data for the monitored wells is also contained in Table 4-4. Figures 4-7 and 4-8 are the static water level contour maps for March 31, 1993 for the deep bedrock wells and the shallow overburden monitoring wells, respectively. Although the step test of MW-207 was performed on April 1-2, 1993, the static levels for these dates were not used because the water level measurements obtained on March 31, 1993 prior to pumping would be most representative of static conditions.

As shown in both Maps 4-7 and 4-8, the direction of groundwater flow under static conditions is from north to south. The static flow conditions are discussed in the beginning of Section 4.2.2.2 of this report.

4.2.2.3 Drawdown Groundwater Flow - Second Phase

For the step drawdown test of MW-202, Figures 4-9 and 4-10 are the drawdown water level contour maps for March 31, 1993 for the deep bedrock wells and the shallow overburden monitoring wells, respectively. The cone of depression maps for maximum pumping conditions are included as Figures 4-11 and 4-12.

At maximum drawdown conditions during the step drawdown test of MW-202, the groundwater flow in both aquifers remained consistent with the static flow conditions with the exception of the area immediately surrounding MW-202. The water table in the deep bedrock aquifer (Figure 4-9) was depressed greatly at MW-202, however the depression did not significantly affect the flow regime at nearby wells (W-30) Parella and MW-207. The groundwater elevation contours were not noticeably affected for the shallow overburden aquifer, as shown in Figure 4-10.

During the pumping of well MW-202, the effect of the dewatering of the bedrock and the glacial till above the pumping well was observed as a cone of depression centered on the pumping well. The cones of depression for maximum drawdown achieved during the step-drawdown test of MW-202 are shown on Figures 4-11 and 4-12 for the deep bedrock wells and the shallow overburden monitoring wells, respectively.

During pumping of MW-202, the water level rose (negative drawdown) in many of the bedrock and shallow wells. The barometric pressure remained relatively steady at 30.1 inches throughout the duration of the test and therefore the rise is due to some other influence. On March 31, 1993, the day of the test, the temperature was in the 60's (degrees F), which was much warmer than the preceding days. The rise in the water table may be a result of increased melt water, which occurs independently of the pump test. The negative drawdown values therefore were not used for the cone of depression maps.

For the deep bedrock aquifer, the cone of depression extended north from MW-202 to W-7 and south towards the wetlands. A cone of depression, centered on the pumping well, was developed in the bedrock, however it was not extensive. At the end of the pump test, the water level in pumping well MW-202 had been drawn down approximately 99 feet. Positive drawdown in the monitored deep wells during pumping was as follows: W-7 (0.23 feet); W-8 (0.09 feet); W-30 (0.75 feet); W-32 (0.11 feet); and MW-207 (0.27 feet). The remaining bedrock wells showed negative drawdown.

Minor till dewatering was observed in MW-2 (immediately adjacent to MW-202) where the water level elevation dropped 0.08 feet at maximum drawdown conditions. Positive drawdown in the monitored shallow wells during pumping was as follows: MW-7 (0.03 feet); MW-8 (0.06 feet); and MW-18 (0.02 feet). The remaining shallow wells showed negative drawdown.

The cone of depression maps indicate that the pumping of MW-202 has very little effect on the flow of the shallow aquifer or the bedrock aquifer.

For the step test of MW-203, Figures 4-15 and 4-16 are the drawdown water level contour maps for December 22, 1992 for the deep bedrock wells and the shallow overburden monitoring wells, respectively. For the step test of MW-203, at maximum drawdown conditions, the groundwater flow in both aquifers remained consistent with the static flow conditions with the exception of the area immediately surrounding MW-203. The water table in the deep bedrock aquifer (Figure 4-15) was depressed greatly at MW-203, however the depression did not significantly affect the flow regime at nearby wells MW-4 and MW-18. The groundwater elevation contours were not noticeably affected for the shallow overburden aquifer, as shown in Figure 4-16.

During the pumping of well MW-203, the effect of the dewatering of the bedrock and the glacial till above the pumping well was observed as a cone of depression centered on the pumping well. The cone of depression maps for the deep bedrock aquifer and the shallow aquifer at maximum pumping conditions are included as Figures 4-17 and 4-18.

For the deep bedrock aquifer, the cone of depression extended in a linear trend east towards the Contel well located at 306-314 Highland Avenue and also in a linear trend north towards W-30 (Parella well located at 320 Highland Avenue) from the Contel/MW-203 linear trend. Deep monitoring wells MW-202 and MW-207, which are positioned between MW-203 and W-30, had minor drawdown, which indicates that the pumping of MW-203 influences W-30 by linear flow or by a combination of radial and linear flow.

The slope and direction of groundwater flow was not changed greatly during the pumping of well MW-203. A cone of depression, centered on the pumping well, was developed in the bedrock. At the end of the pump test, the water level in pumping well MW-203 had been drawn down approximately 113 feet. Drawdown in the monitored deep wells during pumping was as follows: MW-204 (0.65 feet); W-30 (0.38 feet); Contel well (0.14 feet); MW-202 (0.02 feet) and MW-207 (0.08 feet).

The till dewatering was observed in MW-3 (immediately adjacent to MW-203) where the water level elevation dropped from 622.82 feet MSL to 620.37 feet MSL (2.45 feet drawdown) at maximum drawdown conditions. Besides MW-3, no other well had more than one foot of drawdown at the end of the test. Drawdown in the monitored shallow wells during pumping was as follows: MW-3 (2.45 feet); MW-16 (0.30 feet); MW-11 (0.12 feet); MW-4 (0.04 feet); MW-2 (0.02 feet) and MW-13 (0.04 feet). During the step test, the water level rose approximately 0.02 feet (negative drawdown) in MW-14 and 0.16 feet in MW-18, which indicates that the data may be unreliable due to water level collection error (either manual or data logger) or that there is an independent influence affecting the water levels, such as change in barometric pressure. At this point, the reason for these negative drawdown values has not been confirmed.

For the step drawdown test of MW-207, Figures 4-19 and 4-20 are the drawdown water level contour maps for April 2, 1993 for the deep bedrock wells and the shallow overburden monitoring wells, respectively. The cone of depression maps for maximum pumping conditions achieved at the end of the test on April 2, 1993 are included as Figures 4-21 and 4-22.

At maximum drawdown conditions during the step drawdown test of MW-207, the groundwater flow in the bedrock aquifer remained consistent with the static flow conditions with the exception of the area immediately surrounding MW-207. The water table in the deep bedrock aquifer (Figure 4-19) was depressed greatly at MW-207, which caused the groundwater surface to be lowered to the north of the well. The depression affected the flow regime at nearby wells W-30 (Parella) and MW-202 the most. The groundwater elevation contours were not noticeably affected for the shallow overburden aquifer, as shown in Figure 4-20.

During the pumping of well MW-207, the effect of the dewatering of the bedrock and the glacial till above the pumping well was observed as a cone of depression centered on the pumping well. The cones of depression for maximum drawdown achieved during the step-drawdown test of MW-207 are shown on Figures 4-21 and 4-22. The drawdown values for the step test are based on the initial and final water levels measured for April 2, 1993.

For the deep bedrock aquifer, a significant cone of depression (more than a foot of drawdown) extended to W-33 (Contel), W-7 (Cornelius) and MW-204. All of the bedrock wells, with the exception of MW-14, had drawdown. The most notable drawdown was observed in wells MW-202 (10.31 feet), MW-13 (7.12 feet), W-32 (7.05 feet), W-30 (6.14 feet), W-7 (3.14 feet), W-1 (2.39 feet) and MW-204 (1.08 feet). The remaining wells had less than 1 foot of drawdown.

Till dewatering was observed in several wells adjacent to MW-207, however the area of influence observed in the shallow aquifer was not as significant as that in the bedrock aquifer. Only wells MW-2 (2.73 feet), MW-7 (2.12 feet) and MW-10 (1.84 feet) had more than a foot of drawdown. The remaining wells, with the exception of MW-3, had minor, but measurable drawdown.

4.2.3 Aquifer Tests

4.2.3.1 General Procedures

The step-drawdown test was conducted as a short term test at wells W-30 (Parella at 320 Highland Avenue), W-31 (Electra at 328-332 Highland Avenue), W-33 (Contel at 306-314 Highland Ave), W-17 (Barry at 309 Highland Avenue), W-18 (Ruppert at 307 Highland Avenue), W-8 (Osbourne at 329 Highland Avenue), W-1 (Perez at 338 Highland Avenue) and shallow monitoring bedrock monitoring wells MW-202, MW-203 and MW-207. Prior to the start of the test, the static water levels in the test well and selected observations wells were measured. In addition, the water level in the test well was continuously monitored with a Terra 8 channel data logger, with the exception of MW-202 and MW-207. For the tests of MW-202 and MW-207 the data logger was not operational and therefore water levels were manually monitored with an electronic water level indicator. Water level measurements collected with a data logger are preferable to manual readings, however manual readings are reliable because the ultimate goal of a step test is to determine maximum drawdown in observation wells and to determine a stabilized water level at each step. The water level in the pumping well was monitored frequently to record drawdown and to determine if the water level stabilized. No step discharge rate was increased unless stabilization was observed with manual water level measurements. The total depths of the wells were measured with a weighted tape in order to estimate the installation depths for the pump and pressure sensitive probes.

Each of the step-drawdown tests began at a relatively low pumping rates. The pumping rate was held constant until a stable water level was attained in the pumping well. The pumping well drawdown at each step rate was monitored by viewing the data logger computer screen or by manual readings (step tests of MW-202 and MW-207). When the drawdown stabilized, the pumping rate was increased.

The pumping rate steps ranged from ½ to 15 gallons per minute (gpm). The pumping rate of the submersible pump in the drawdown well was relatively constant during the step rate. The discharge from the pumping well was maintained constant at each step by monitoring the in-line flow meter and adjusting the control valve accordingly. To ensure the accuracy of the flow meter readings, the discharge was measured periodically with a pre-calibrated 5 gallon bucket and stop watch. Groundwater pumped during the step-drawdown test was transferred to a holding tank staged on-site for later treatment.

Baseline monitoring of all instrumented wells was initiated before the test. Constant water level readings were noted during baseline monitoring, indicating that the aquifer was at static conditions.

The pumping-induced cone of depression was continuously monitored throughout each test. Nearby wells were selected as water level observation points during each step-drawdown test. The selected observation wells and the pumping well, were equipped with pressure-sensitive transducers which were connected to a Terra-8 channel data logger. Each pressure-sensitive transducer was calibrated to ensure that the rated depth of installation did not exceed each probe's sensitivity range. The installation depth, rated probe pressure and the height of water column above the probe were recorded prior to the start of the test. The remainder of the site wells were monitored manually with electronic water level indicators. The well monitoring information, which includes probe installation data, is included in Tables 4-5 and 4-6 for the first and second phase step tests, respectively.

All the pumping wells and the nearby observation wells were continuously monitored with pressure-sensitive transducers and a Terra 8 channel data logger. The monitoring frequency was designed to measure the early drawdowns of the first step of each test at variable time intervals. The remainder of the steps were monitored at different variable time intervals. The drawdown data for the logged wells for the first and second phase step tests are presented in Appendices 4-B and 4-C, respectively.

The more remote observation wells were manually monitored with electronic water level indicators. Each remote observation well was monitored three times at a minimum: once before the test, during the test and prior to the end of the test. For the first and second phases of step-drawdown tests, the maximum drawdowns for the observation wells are summarized in Tables 4-3 and 4-4, respectively. The cone of depression maps for each step test are included as Figures 4-1 through 4-6 and Figures 4-11, 4-12, 4-17, 4-18, 4-21 and 4-22.

4.2.3.2 Observations - First Phase

Well W-30 (Parella) was initially step-tested at a discharge rate of 2 gpm. A submersible pump was installed at a depth of 90 feet below grade and a pressure-sensitive transducer was installed at a depth of 76 feet below grade. Approximately 60 feet of water was recorded above the transducer probe before initiating the test. The test lasted for approximately 1 hour, as the pump intake was uncovered at a pumping rate of 2 gpm. The recovery phase was initiated at the end of the test and lasted for approximately 2 hours. Because of the poor response of the well, as observed during the initial test, pumping continued at a lower rate from well W-30 (Parella) for approximately 4 hours after the test ended to further develop and enhance the well's performance.

Well W-30 (Parella) was later developed using air surging method to clean out the fractures. Information obtained after the well was properly developed indicates that the efficiency of well W-30 (Parella) is greatly enhanced by proper well development and maintenance.

Because W-30 (Parella well) was the prime candidate for the long-term pump test, the well was re-tested on June 22, 1992, in order to obtain additional information regarding well efficiency and sustainable yield. The second test was initiated at a pumping rate of ½ gpm, during which the water level in the well stabilized within 5 minutes. The discharge rate was increased to 1 gpm and the water level stabilized in approximately 10 minutes. The pump was then turned up to 2 gpm and after 30 minutes had stabilized with almost 60 feet of drawdown.

The remainder of the selected wells, with the exception of well W-31 (Electra), were similarly step-tested starting at a discharge rate of 2 gpm with 2 gpm increments to a maximum of 8 gpm or when the pump intake was uncovered. Well W-31 (Electra) was step-tested with discharge rates of 1, 2, 3, 4, 6 and 8 gpm.

The data for each step test, which is contained in Appendix 4-B. was evaluated for indication of water level stabilization. The highest sustainable pump discharge rate that induced a stable water level, which is the optimum discharge rate, was noted. Based on the results, it appears that W-1 can sustain 6 gpm, W-8 can sustain 2 gpm, W-17 can sustain 2 gpm, W-18 can sustain 2 gpm, W-30 can sustain 2 gpm, W-31 can sustain 6 gpm, and W-33 can sustain 6 gpm. A pumping rate higher than the optimum rate causes the pump to become uncovered.

4.2.3.3 Observations - Second Phase

Summaries of discharge rate monitoring for each of the second phase step tests are included in Table 4-7.

The step drawdown test of MW-202 was conducted on March 31, 1993. MW-202 and seven adjacent wells were outfitted with data logger probes in order to monitor the drawdown. The data logger was not functional, and therefore the probes were removed and all wells were manually monitored.

The test was started at 13:32 and was completed at 18:28. The test was started at ½ gpm and the water level never stabilized, which indicates that the well cannot produce even ½ gpm. The test could not have been conducted at a lower discharge rate without causing the discharge flow to be intermittent. MW-202 was pumped at ½ gpm for 296 minutes, which produced approximately

150 gallons of water from the well during the test. The standing water column removed from the well was approximately 128 gallons (88 feet of drawdown multiplied by 1.47 gallon/feet), which means that only 22 gallons of water was removed from the formation.

The monitoring data (time drawdown) obtained for the step drawdown test of the pumped well (MW-202) is contained in Appendix 4-C.

The step-drawdown test on MW-203 was conducted December 22, 1992. The pumping well (MW-203) and observation wells MW-4, MW-11, MW-16, MW-18, MW-204 and MW-207 were monitored with the data logger. Wells MW-2, MW-3, MW-13, MW-14, MW-15, MW-202 and 306-314 Highland Avenue (Contel) were monitored manually. Water level measurements were obtained prior to the start of the test to serve as baseline measurements. Wells were monitored throughout the test to evaluate the progress and maximum extent of drawdown.

The probes were installed in the wells and baseline measurements with the data logger began at 07:32. During this time, manual water level measurements were obtained from the probe-instrumented wells.

At 08:00 the step-drawdown test began at a pumping rate of 1.5 gpm. At 09:48 the generator ran out of gasoline and the pump shut off for approximately 10 minutes, whereafter an alternate power source was located. The pump was restarted and by 10:18 the pumping rate was restored to 1.5 gpm. The water level in MW-203, initially at 2.681 feet below ground surface was drawn down to approximately 17 feet below ground, where it stabilized from 10:38 to 12:00. At 12:00 the pumping rate was increased from 1.5 to 4 gpm. The drawdown dropped substantially from 17 feet to greater than 100 feet below ground surface. The probe was uncovered at 105.25 feet below ground surface at 13:23. The pump intake was uncovered at approximately 113 feet below ground surface at 13:57 at which time the pump was shut off. The monitoring data (time drawdown) obtained for the instrumented wells for the entire test and for the drawdown phase are contained in AppendiX 4-C.

Drawdown was observed in all monitored wells during the step-drawdown test. The drawdown in the monitored wells ranged from more than 110 feet in MW-203 (the pumping well) to less than 0.02 feet of drawdown in peripheral wells. The maximum drawdowns for the observation wells are summarized in Table 4-4.

The groundwater elevations in the deep bedrock and shallow aquifers under maximum drawdown conditions, achieved at 13:57, were plotted on site maps and contoured (Figures 4-9 and 4-10). In addition, the drawdown values were contoured on Figures 4-11 and 4-12 to show the cone of depression for the step-drawdown test.

The groundwater contour results indicate that MW-203 did not influence a large area at maximum drawdown conditions. This, however, may be due to the limited amount of time that MW-203 was pumped. In addition, the observation of drawdown is hampered by the lack of monitoring wells in the area of MW-203, especially to the north and northeast.

The discharge rate of 1.5 gpm produced a steady drawdown in well MW-203. At a discharge rate of 1.5 gpm, the water table was lowered approximately 15 feet and was held relatively constant for almost 3 hours. The drawdown at 4 gpm, however, did not stabilize at any point in the test. The pump was uncovered after 2 hours of pumping at 4 gpm, thereby indicating that the well was not able to sustain a discharge rate of 4 gpm.

The step-drawdown test of MW-203 was conducted in order to determine suitable wells for the long term pump test of well W-30 (Parella). The drawdown achieved during the step test was most pronounced in wells MW-204, W-30 (Parella) and W-33 (Contel), all of which were monitored during the long term pump test of W-30. During the step test, wells MW-3 and MW-16 showed notable drawdown, however the importance of this data may be underscored because these wells are close to MW-203 and therefore significant drawdown in these wells is expected.

The step drawdown test of MW-207 was conducted on April 1-2, 1993. The test was started at 10:22 on April 1, 1993 at a discharge rate of ½ gpm. The water level at ½ gpm stabilized at a depth of 3.67 feet after 43 minutes and the discharge rate was increased to 1 gpm. After 37 minutes the water level stabilized at 5.21 feet below grade. The third step, at 1½ gpm, stabilized at 6.83 feet after 63 minutes. The fourth step, at 2 gpm, stabilized at 8.26 feet after 50 minutes. The pump was turned off at 13:27 for one minute to install a flow meter. The flow meter, which is calibrated for 15 gpm, does not register flow rates below 3 gpm, and therefore was not installed for the initial steps of the test. The fifth step, at 4 gpm, stabilized at 14.65 feet after 81 minutes. When the pump discharge rate was increased to 6 gpm, the increased back pressure caused the discharge pipe to be disconnected, but this situation was corrected after 15 minutes. The sixth step, at 6 gpm, could not be completed because the pump could not maintain a constant discharge rate. The test was stopped at 17:30.

A 15 gpm-rated submersible pump was installed in MW-207 on April 2, 1993 in order to achieve higher discharge rates. Step 6, at 6 gpm, was repeated. After 79 minutes, the discharge stabilized at 15.48 feet. The seventh step, at 8 gpm, stabilized at 25.46 feet after 83 minutes. The eighth step, at 10 gpm, stabilized at 36.57 feet after 67 minutes. The ninth step, at 12 gpm, stabilized at 49.70 feet after 41 minutes. The tenth step, at 15 gpm, exceeded the storage and treatment capacity of the pilot treatment system after 32 minutes. The water level was beginning to stabilize and the well was not fully stressed, therefore the well can potentially produce more than 15 gpm.

The monitoring data (time drawdown) obtained for the pumped well (MW-207) for the step drawdown test is contained in Appendix 4-C.

4.2.4 Data Analysis

4.2.4.1 Step-Drawdown Data Analysis

Step-drawdown tests are useful for evaluating the magnitude of turbulent head loss for the purpose of determining optimum pumping rates (Driscoll, 1987). Analysis of the step-drawdown test data consisted of plotting the drawdown versus time on a semi-logarithmic graph to determine the incremental drawdown caused by a change in pumping rate (pumping rate is represented by Q in feet^3 per minute). Values of delta s (change in drawdown) and delta Q (change in discharge rate) were calculated from the field data.

The well losses and the aquifer losses can be evaluated using the following equation (Jacob, 1950):

$$s_w = BQ + CQ^2$$

Where the theoretical drawdown, s_w, equals the sum of the laminar aquifer loss component (BQ) and the turbulent well loss component (CQ^2). The data for s/Q versus Q are plotted on arithmetic graph paper in order to determine the values of B and C. This equation can be rearranged to provide the following linear equation:

$$s_w/Q = B + CQ$$

Plotting s_w/Q against Q results in a graph with a straight line from which the values of B and C can be obtained. B is the value of the intercept of the line with the s/Q axis; and the value of C is the slope of the line (Bierschenk, 1963). Therefore, B and C can be estimated from the graph.

Inverting this equation gives Q/s_w, which is specific capacity of the pumping well. Specific capacity of a well describes the productivity of both the aquifer and the well (Kruseman and de Ridder, 1990). With this formula, the relationship between discharge rate and drawdown becomes apparent. An increase in the discharge rate Q, results in a decrease of the specific capacity. In addition, at a constant discharge rate, the specific capacity will decrease over time, since specific capacity is a function of both time and discharge.

The percentage of the total head loss attributable to laminar flow, represented by L_p, can be written as:

$$L_p = \frac{BQ}{BQ + CQ^2} \cdot 100\%$$

The total head loss attributable to laminar flow therefore represents the formation loss (BQ) divided by the total of the well loss and formation loss ($BQ + CQ^2$). High L_p values indicate that the total head loss is due primarily to formation loss, whereas low L_p values are indicative high well losses (low formation loss).

Since the long term pump test of well W-30 (Parella) has been conducted, the step test recovery data is not needed and therefore will not be analyzed.

4.2.4.2 Well Data Analysis - First Phase

The data for the first phase step-drawdown tests were plotted on semi-logarithmic graphs of drawdown (s) versus time (t), to determine the incremental drawdown caused by a change in pumping rate. Values of s/Q versus Q for each step test were plotted on arithmetic graphs to determine values of B and C. The graphs of drawdown versus time, s/Q versus Q, and drawdown versus time for each of the pumped wells are included as Graphs 4-14 through 4-34.

Results of the step-drawdown analysis on well W-30 (Parella) indicate that a pumping rate of 2 gpm could produce a theoretical drawdown of approximately 76 feet, assuming steady state conditions. Approximately 71 feet of drawdown was caused by formation losses and 5 feet of drawdown was caused by well losses in the pumping well.

Similarly, pumping W-1 (Perez) at a rate of 6 gpm could produce a theoretical drawdown of 12.9 feet with formation losses accounting for 0.3 feet of drawdown and well losses accounting for 12.6 feet of drawdown. Pumping W-8 (Osbourne) at a rate of 4 gpm could produce a theoretical drawdown of 140 feet with formation losses accounting for 122 feet of drawdown and well losses accounting for 18 feet of drawdown.

Pumping W-17 (Barry) at a rate of 6 gpm could produce a theoretical drawdown of 146 feet with formation losses accounting for 75 feet of drawdown and well losses accounting for 71 feet of drawdown. Pumping W-18 (Ruppert) at a rate of 6 gpm could produce a theoretical drawdown of 156 feet with formation losses accounting for 122 feet of drawdown and well losses accounting for 34 feet of drawdown.

Pumping W-31 (Electra) at a rate of 8 gpm could produce a theoretical drawdown of 55 feet with formation losses accounting for 2.3 feet of drawdown and well losses accounting for 52.8 feet of drawdown. Pumping W-33 (Contel) at a rate of 8 gpm could produce a theoretical drawdown of 60 feet with formation losses accounting for 30 feet of drawdown and well losses accounting for 30 feet of drawdown.

The calculated results for specific capacity (Q/s), L_p percentage and theoretical drawdown, are summarized in Table 4-8.

4.2.4.3 Well Data Analysis - Second Phase

The data for the step-drawdown test of MW-202 was plotted on a semi-logarithmic graph of drawdown (s) versus time (t), included as Graph 4-35, to determine the incremental drawdown caused by a change in pumping rate. From the graph, it is apparent that the drawdown at ½ gpm did not stabilize, thereby indicating that the well was not able sustain a discharge rate of ½ gpm.

Since the water level never stabilized, values of s/Q versus Q cannot be plotted and values of B and C cannot be calculated. Based on the test results, it is apparent at a pumping rate of ½ gpm the L_p for MW-202 approaches zero, which indicates that the total head loss is attributed primarily to well loss with minor formation loss. The test results are summarized in Table 4-8.

Although the data can not be accurately evaluated for specific capacity and laminar flow component, the test results are very useful. The intent of the step tests is to determine optimum discharge rates and determine the extent of influence on surrounding wells. From this test, it is apparent that MW-202 cannot sustain even very low pumping rates and that it does not significantly influence surrounding wells.

The data for the step-drawdown test of MW-203 was plotted on a semi-logarithmic graph of drawdown (s) versus time (t), included as Graph 4-36, to determine the incremental drawdown caused by a change in pumping rate. From the graph, it is apparent that the drawdown at 4 gpm did not stabilize. The pump was uncovered at a depth of 113 feet, thereby indicating that the well was not able sustain a discharge rate of 4 gpm.

Values of s/Q versus Q was plotted on an arithmetic graph, which is included as Graph 4-37. From Graph 4-37, values of B and C were calculated. Although a straight line plotted through the actual field data points will intercept Q = 0 feet^3 per minute at B = -5.17, this is not possible because it indicates that when the well is not being pumped there is negative drawdown. Therefore, the line was arbitrarily plotted through s/Q = 75.10 and the origin, thus resulting in a value of B = 0. Using a B value of zero, the L_p for MW-203 becomes 0%, which indicates that the total head loss is attributed solely to well loss with no formation loss. The calculated results are summarized in Table 4-8.

The specific capacity (Q/s) of MW-203 for a discharge rate of 1.5 gpm is 0.013 $feet^2$ per minute and for a discharge rate of 4.0 gpm is 0.0048 $feet^2$ per minute.

The data analysis is based on a minimal number of pumping steps, and therefore may result in differences between the actual and theoretical values for drawdown and the total head loss attributable to laminar flow. In addition, the drawdown at a discharge rate of 4 gpm did not stabilize, therefore the data obtained from this drawdown step will not be reliable. For future tests, the step-drawdown discharge increment will be reduced so that there are more steps. Increasing the number of step will provide more data points, which will improve the reliability of the data. In addition, future tests will be conducted so that at each step the drawdown will be allowed to stabilize prior to increasing the discharge rate.

The data for the step-drawdown test of MW-207 was plotted on a semi-logarithmic graph of drawdown (s) versus time (t), included as Graph 4-38 (two pages), to determine the incremental drawdown caused by a change in pumping rate. From the graphs, it is apparent that the drawdowns stabilized at all pumping rates, with the exception of the 15 gpm rate. At 15 gpm, the water level started to become stable thereby indicating that the well may be able sustain a discharge rate of 15 gpm.

Values of s/Q versus Q was plotted on an arithmetic graph, which is included as Graph 4-39. From the graph, values of B and C were calculated. A straight line was plotted through the field data points, and the slope of the resulting line has a value of C = 1.99. The point at which the line intersects Q = 0 is B = 22.73. Using a B value of 22.73, a C value of 1.99 and a Q of 1.95 $feet^3$ per minute (15 gpm), the L_p for MW-207 becomes 85.4%. The calculated results are summarized in Table 4-8.

The specific capacity (Q/s) of MW-207 ranges from 0.033 $feet^2$ per minute for a discharge rate of 12 gpm to 0.059 $feet^2$ per minute for a discharge rate of 6 gpm.

4.2.4.4 Overall Step-Drawdown Results

The ratio L_p, which denotes the percentage of the total head loss attributable to laminar flow, was calculated for all tested wells; the results are summarized in Table 4-8. Referring to Table 4-8, the value of L_p ranged from 0% in MW-203 to 93% in W-30 (Parella), indicating the percentage of the head loss caused by well inefficiency that is associated with laminar flow varies greatly. Well efficiency varies not only with the pumping rate and the time of pumping, but also changes with the saturated thickness and recharge characteristics of the aquifer.

The average specific capacity of each well is also summarized in Table 4-8. For the first phase of step tests, the average specific capacity ranged from 0.0040 ft^2/min in W-30 (Parella) and W-8 (Osbourne) to 0.120 ft^2/min in W-1 (Perez).

It should be noted for MW-203 that the data analysis is based on a minimal number of pumping steps and therefore may result in differences between the actual and theoretical values for drawdown and the total head loss attributable to laminar flow. A perfectly constructed well will exhibit a value of B greater than zero since this is the laminar flow component, and all aquifers have some laminar flow resistance. A well will exhibit turbulent flow resistance only when improperly constructed and developed or when deterioration occurs.

In addition, the drawdown in MW-203 at a discharge rate of 4 gpm did not stabilize, therefore the data obtained from this drawdown step will not be reliable. For future tests, the step-drawdown discharge increment will be reduced so that there are more steps. Increasing the number of steps will provide more data points, which will improve the reliability of the data. In addition, future tests will be conducted so that at each step the drawdown will be allowed to stabilize prior to increasing the discharge rate.

4.2.5 Conclusions and Recommendations

Because well W-30 (Parella) is considered a prime candidate for the long-term pump test, the well was further developed using air surging method to enhance its performance. The sustainable yield of W-30 increased to 2 gpm as a result of proper development.

The results of the Phase I step-drawdown tests provided confirmatory data for evaluating the ability of the wells to sustain optimum pumping rates. The sustainable yields ranged from 2 gpm in wells W-8 (Osbourne), W-17 (Barry), W-18 (Ruppert), and W-30 (Parella) to 6 gpm in wells W-1 (Perez), W-31 (Electra) and W-33 (Contel).

The groundwater contour results indicate that the step tests of MW-202 and MW-203 did not influence a large area at maximum drawdown conditions. For MW-203, this may be due to the limited amount of pumping time. In addition, the observation of drawdown is hampered by the lack of monitoring wells in the area of MW-203, especially to the north and northeast. The step test of MW-202 did not influence a large area due to its inability to produce appreciable amounts of water.

The step test of MW-202 showed that the well is not capable of producing even ½ gpm, thus MW-202 would not be a suitable well for long term pumping.

For MW-203, a discharge rate of 1.5 gpm produced a steady drawdown in well MW-203. At a discharge rate of 1.5 gpm, the water table was lowered approximately 15 feet and was held relatively constant for almost 3 hours. The drawdown at 4 gpm, however, did not stabilize at any point in the test. The pump was uncovered after 2 hours of pumping at 4 gpm, thereby indicating that the well was not able to sustain a discharge rate of 4 gpm.

Well MW-207 was able to produce from ½ to 15 gpm. The water level was starting to stabilize at 15 gpm, thereby indicating that MW-207 can potentially produce a higher yield.

Drawdown data collected from the observation wells provided an indication of the radial influence of the tested wells on the bedrock aquifer system. The data further suggest that pumping from one well, probably W-30 (Parella), may not be capable of developing a cone of depression necessary to encompass the contaminant plume and define linear trends or fractures that are known to exist at the site (See Figure 7 and Section 2, pg 2-8) of RSAMP).

Based on the drawdown data obtained during the step-drawdown test, fifteen wells optimally located around the pumping center (W-30) were instrumented to monitor and record changes in water level during the long-term pump test.

The fifteen wells used as observation wells for the long term pump test are:

W-7 (Cornelius 330 Highland Avenue)
W-8 (Osbourne 329 Highland Avenue)
W-13 (Wood 319 Highland Avenue)
W-14 (Knapp 317 Highland Avenue)
W-17 (Barry 309 Highland Avenue)
W-18 (Ruppert 307 Highland Avenue)
W-19 (Rasmussen 187 Watkins Avenue)
W-26 (Robaina 297 Highland Avenue)
W-31 (Electra 328-332 Highland Avenue)
W-32 (Stout 316 Highland Avenue)
W-33 (Contel 306-314 Highland Avenue)
MW-202
MW-203
MW-204
MW-207

The wells listed above were monitored with pressure-sensitive transducers during the long-term pump test. The remainder of the nearby residential and monitoring wells, including W-1 (Perez) and W-11 (Gilbert) and the more remote residential wells were manually monitored with electronic water level indicators during the long-term pump test.

4.3 LONG-TERM PUMP TEST

4.3.1 Introduction

In accordance with the approved Revised Sampling, Analysis and Monitoring Plan ("RSAMP") dated April 22, 1992, a long-term pump test on well W-30 (Parella) was conducted at the General Switch site. The long-term pump test consisted of 2 days of baseline monitoring, 3 days of pumping, and 2 days of recovery monitoring. The entire test was conducted from October 13 to October 19, 1992.

The pump test was performed to determine the aquifer characteristics of the bedrock aquifer. The aquifer characteristics will be used to calculate the effective radius of influence of a groundwater recovery system operating at the optimum pumping rate. Prior to the long-term pump test, step-drawdown tests were performed on pumping well W-30 and six other residential wells for the purpose of determining the optimum pumping rate that could be sustained for the duration of a long-term aquifer pump test. In addition, the test results of the step-drawdown tests were used to select observation wells for monitoring purposes for the long-term (3-day) pump test of well W-30.

This report sets forth the pump test setup and operation, the hydrogeologic results, calculations of aquifer characteristics, and interpretations of the findings. The results and conclusions obtained will be evaluated in conjunction with the other RSAMP study results in order to assess the suitability of using W-30 as a groundwater recovery well for the remedial action.

4.3.2 Groundwater Contours and Flow Directions

Water level data was obtained from residential and monitoring wells at the study area prior to and during the long-term pump test. The water levels, which are summarized in Table 4-11, were converted to water elevations by subtracting the depth to water from the well casing elevations, which were previously surveyed by a licensed surveyor. The groundwater elevations for both pre-pumping conditions (static) and at maximum drawdown during pumping of well W-30 (Parella) were plotted and contoured. Maps 4-A and 4-B contain the static water level contour maps for the deep bedrock monitoring and residential wells, and for the shallow unconsolidated monitoring wells, respectively. The drawdown maps and for the deep bedrock monitoring and residential wells, and for the shallow unconsolidated monitoring wells are included as Maps 4-C and 4-D, respectively.

Table 4-1 contains well completion data, such as total depth, screened or open interval, ground surface elevation, casing elevation, and screen elevation. In order to aid in the evaluation of the hydrogeology at the site, geologic cross sections have been prepared and are included in the site characterization section of this report. The cross sections include stratigraphy, well screened intervals or open intervals, static groundwater levels and any of available information on fracture occurrence.

4.3.2.1 Static Groundwater Flow

The monitoring wells installed into the top 25 feet of bedrock were not mapped for the following reasons. First, the shallow bedrock wells are drilled into the top of bedrock, therefore it would be inappropriate to map the groundwater elevations of these wells with the other bedrock wells which are drilled into a deeper bedrock zone. Second, although the surface of the shale bedrock may be fractured and degraded, the groundwater within the top portion of the bedrock may not necessarily flow in a manner consistent with unconsolidated sediments. Based on the foregoing, it would be appropriate to map the shallow bedrock wells as a separate hydrogeologic unit. Since there are only four shallow bedrock wells, and these wells are positioned approximately in a line, the contour map developed from the data may not be reliable and therefore will not be developed.

The direction of groundwater flow under static conditions, in the shallow monitoring wells (screened in the glacial till to the top of bedrock) is from north to south. The groundwater elevations decrease from 637.28 feet mean sea level (MSL) at MW-1 to 609.89 feet MSL in MW-4. The general trend of the groundwater table follows the slope of the hillside from north to south and toward the wetlands.

Wetlands can indicate groundwater is potentially discharging at the ground surface. The wetlands at the site lies at an elevation between 620 and 612 feet MSL, which is higher than the groundwater elevation (609.89 feet MSL) at MW-4, the well immediately adjacent to the north side of the wetlands. In addition, the depth to water at MW-4 is approximately 9 feet below ground surface, therefore it is unlikely that the shallow groundwater in the till discharges at the wetlands. It is possible that the water in the wetlands results from a perched water table independent of the shallow till water table. The water level in the wetlands has not been measured and there are no surveyed benchmarks in the wetlands and therefore standing water in the wetlands can not be reliably evaluated with the shallow groundwater elevations and contour map. Section 4.3.4.5 of this report discusses the vertical hydraulic gradients in regard to the wetlands.

Although a contour map has not been developed for the shallow bedrock wells, there is, however, a notable anomaly in the groundwater surface in the area of MW-14. The open interval of MW-14 is from 70 to 80.65 feet below ground surface. The static water level elevation of MW-14 is 570.96 feet MSL, which is much lower than the closest upgradient shallow bedrock well, MW-13 (elevation 617.46 feet MSL). The hydraulic gradient between MW-14 and MW-13 is approximately 0.29 (617.46 ft - 570.96 ft/160 ft), which is significantly higher than the approximate site hydraulic gradient of 0.065. This depression of the water level in MW-14 is confirmed both by the recovery data and the static water levels taken during the first and second rounds of groundwater samples for this well. At this time, the cause of this anomaly is unconfirmed, however it could be due to decreased horizontal hydraulic conductivity between wells MW-13 and MW-14, which would steepen the horizontal gradient between the wells, or it could be due to the possibility that MW-14 is installed into bedrock that does not intercept the same fracture system as the other monitoring wells. Another possible explanation is that MW-14 intercepts a fracture system that is being pumped by a residential well not being monitored as part of the site investigation. This explanation would account for drawdown and recovery in MW-14 that is apparently unrelated to the pumping and recovery of W-30.

The groundwater elevations plotted under static conditions for October 14, 1992, for the deep bedrock residential wells and the 200 series bedrock monitoring wells indicate that, compared to the groundwater elevations plotted in 1983 and 1984, the groundwater contours indicate a more regular trend that mirrors both the shallow groundwater contours and the site topography. Static groundwater contours in the bedrock decrease in a north to south direction from an elevation of 634.48 feet MSL in W-8 (Osbourne) and 636.70 feet MSL in W-31 (Electra) to 611.48 feet MSL in MW-204 and approximately 605 feet MSL in the Rasmussen, Robaina and Petruzzio (Sleiter) wells to the west of the site. Thus, the regional direction of natural groundwater flow in the bedrock is from north to south, down the valley.

4.3.2.2 Drawdown Groundwater Flow

As was expected, the slope and direction of groundwater flow changed during the pumping of well W-30. A cone of depression, centered on the pumping well, was developed in the deep bedrock (Map 4-E). At the end of the pump test, the water level in pumping well W-30 had been drawn down 45.58 feet. Bedrock wells that were greatly affected (more than 5 feet of drawdown) by the 3 days of pumping included W-7 (Cornelius well, 13.35 feet of drawdown), W-8 (Osbourne, 9.63 feet drawdown) and MW-202 (6.80 feet drawdown). Drawdown in the peripheral wells during pumping was as follows: W-17 (Barry well, 1.19 feet); W-18 (Ruppert well, 1.10 feet); the Contel well (0.75 feet); W-1 (Electra Manufacturing, 1.79 feet); W-14 (Knapp, 2.62 feet); Stout (2.78 feet); MW-207 (2.45 feet) and W-13 (Wood, 3.79 feet). Bedrock wells that were only marginally affected by the 3-day pumping, with less than 0.5 feet of drawdown, were MW-204 (0.28 feet of drawdown) in the wetlands and MW-203 (0.44 feet) located at the bottom of the slope at the southern edge of the General Switch parking lot.

During the pumping of W-30 (Parella), the effect of the dewatering of the fractured bedrock near the pumping well was observed (Map 4-F). The fractured bedrock dewatering was observed in MW-12 (immediately adjacent to W-30) where the water level elevation dropped 27.27 feet from 624.30 feet MSL to 597.03 feet MSL at maximum drawdown. In addition, drawdown was observed in shallow bedrock well MW-13 at 2.45 feet and in MW-15 at 1.08 feet. During the pump test, the water level in MW-14 rose approximately 1.68 feet (negative drawdown), which indicates that the anomaly centered on MW-14 may be attributed to some other influence other than the pumping of well W-30.

In addition to drawdown in the deep and shallow bedrock wells, there was a cone of depression produced in the shallow unconsolidated overburden deposits (Map 4-G). Monitoring wells with appreciable drawdown include: MW-1 (5.51 feet), MW-7 (2.00 feet), and VES-2 (1.68 feet). All of the other monitoring wells MW-2, MW-3, MW-4, MW-5 and MW-10) had drawdown of less than 1 foot.

4.3.3 Aquifer Test

The 3-day drawdown test, followed by a 2-day recovery test, was performed to determine aquifer characteristics of the bedrock aquifer. The test consisted of three phases: baseline, drawdown and recovery. The information obtained from this test will be used, in conjunction with findings from other components of the RSAMP, for the selection and design of a remedial system. The proposed remedial system will be discussed in the final RSAMP report.

Static water levels were measured in residential wells W-17 and W-18 during the two days (October 12 through October 14) preceding the test to identify water level trends. Baseline monitoring of all instrumented wells was initiated 21 hours before the test. Straight lines were noted in the plot of water levels during baseline monitoring, indicating that no residential wells were being pumped that could influence the pump test during that period. In order to sufficiently stress the bedrock aquifer, the drawdown phase continued for 3 days. The drawdown test was started at approximately 1130 hours on October 14, 1992 and continued until approximately 1130 hours on October 17, 1992. The recovery phase started at the end of the drawdown phase and continued until approximately 0700 hours on October 19, 1992.

The pumping-induced cone of depression was continuously monitored throughout the test. Fifteen monitoring wells were selected as water level observation wells during the pumping test based on the results of the step-drawdown test. The fifteen wells and the pumping well, W-30, were equipped with pressure-sensitive transducers which were connected to two Terra-8 channel data loggers. Each pressure-sensitive transducer was calibrated to ensure that the rated depth of installation did not exceed each probe's sensitivity range. The installation depth, rated probe pressure and the height of water column above the probe were recorded prior to the start of the test. The remainder of the site wells were monitored manually with electronic water level indicators. Table 4-9 contains a summary of the well monitoring information.

The pumping rate of the submersible pump in W-30 was relatively constant, an average of 2 gallons per minute (0.27 cubic feet per minute) was sustained throughout the test. The rate was maintained throughout the test by monitoring the in-line flow meter (Fill-Rite Series 800A) at 30-minute intervals. To ensure the accuracy of the flow meter, the discharge was monitored and measured periodically with a pre-calibrated 5-gallon bucket and a stop watch. A summary of the discharge rate monitoring information is contained in Table 4-10. Through the 72-hour test, approximately 8,600 gallons of groundwater was pumped and staged in two 7,000-gallon tanks for treatment at the site.

Drawdown was observed in all monitored wells during the pump test. The drawdown in the monitored wells ranged from more than 27 feet in MW-12 (located adjacent to the pumping well) to less than 0.5 feet of drawdown in peripheral wells. The maximum drawdowns for the observation wells are summarized in Table 4-11. Graphs 4-40 and 4-42 are graphs that show the relationship of the water table versus time for wells W-30, W-7, W-8, W-31, MW-202, MW-203, MW-204 and MW-207. Graph 4-39 is a graph of drawdown versus time for wells W-30, W-31, W-7, W-8, MW-202 and MW-207. The maximum drawdown maintained in the pumping well (W-30) was 45.583 feet. Wells W-7 (Cornelius), W-8 (Osbourne), W-13 (Wood), W-31 (Electra), 316 Highland Avenue, MW-202 and MW-207 had the greatest drawdown during the pump test and thus were specifically selected for hydrogeologic characterization analysis.

The pump test data for the sixteen logged wells showing date, time, elapsed time, square root of time in minutes, water level and drawdown are presented in Appendix 4-D. Separate summary tables with elapsed time (minutes) versus drawdown for pumping and recovery phases are included in Appendices 4-E and 4-F, respectively. The hydrographs of water level changes versus time in nine of sixteen instrumented wells in response to pumping (Graphs 4-37 and 4-38 illustrate the three phases of the test (baseline, drawdown and recovery) and the delayed response in some of the monitored wells as a result of the pumping. Graph 4-39 shows the relative drawdown versus time for wells W-30, W-31, W-7, W-8, MW-202 and MW-207.

4.3.4 Data Analysis

The water level changes measured in the observation wells in response to the pumping of well W-30 were analyzed by several methods. The data from the drawdown phase were analyzed using equations for linear flow developed by Jenkins and Prentice, 1982. The data from the recovery phase were analyzed using residual-drawdown methods (Theis, 1935). The recovery data analysis was used to check calculations of aquifer characteristics based on linear equations. Based on the initial evaluation of the linear flow analysis, the data was re-evaluated using a non-equilibrium method for leaky confined/semi-confined aquifers (Hantush and Jacobs, 1955).

4.3.4.1 Linear Flow Analysis

To determine if linear flow conditions exist at the site, a graph of drawdown versus square root of time was plotted for each of the seven wells (W-7, W-8, W-13, W-14, W-31, MW-202 and MW-207) that showed the greatest drawdown. These plots are presented in as Graphs 4-43 through 4-49.

For wells W-31 and MW-207, the data plotted along a straight line, indicating that there may be structural influence on groundwater flow at these wells. The linear equation method was used to calculate aquifer transmissivity (T) values for wells W-7, W-8, W-13, W-14, MW-202 and MW-207. The transmissivity values ranged from 2.88 feet^2 per minute to 33.3 feet^2 per minute. Hydraulic conductivity (K) values were calculated from transmissivity values based on the assumption that aquifer thickness is approximately 100 feet which corresponds to the length of saturated open rock hole in W-30 (Parella). Hydraulic conductivity values of 0.0288 feet per minute to 0.333 feet per minute were calculated. The typical range for hydraulic conductivity of shale is 10^{-8} feet per minute to 10^{-12} feet per minute and for fractured rocks it is in the range of 10^{-4} feet per minute to 10^{-7} feet per minute (Driscoll, 1986). The K values obtained for the observation wells far exceed the typical values for similar formations or formations with similar physical characteristics.

The data for wells W-7, W-8, W-13, W-14 and MW-202 plotted in a straight line for the initial drawdown response, but then became non-linear. The graphs for these wells indicated that the drawdown had stabilized after a period of 400 to 1200 minutes. The Jenkins and Prentice method is only valid if the data plots on a straight line for an extended period of pumping. The data indicates that the linear trend disappeared well before the completion of the 3 day pump test, which leads to the conclusion that the primary groundwater flow is not linear through fracture systems. Based on the foregoing results and interpretations, it is apparent that the Jenkins and Prentice method is inappropriate for this application.

Analyses and calculations based on linear flow equations are summarized in Appendix 4-G. The linear analysis results are summarized in Table 4-12.

4.3.4.2 Leaky Confined/Semi-Confined Aquifer Analysis

The data, therefore, required re-evaluation to determine the most appropriate method of determining hydrogeologic properties. The time-drawdown data plotted for these wells was evaluated and the best fit of the time-drawdown data was achieved using the non-equilibrium method for radial flow in leaky confined/semi-confined aquifers (Fetter, 1980). The data for observation wells MW-202, MW-207, W-7, W-8, W-13, W-31 and 316 Highland Avenue well were analyzed by the Hantush-Jacobs method using the AQTESOLV (Duffield and Rumbaugh, 1991) program. The plots for these analyses are presented as Graphs 4-50 through 4-56.

The drawdown results were evaluated for transmissivity (T) and storativity (S). Transmissivity values range from 0.00005 to 0.0405 ft^2 per minute, with a geometric mean of 0.0035 ft^2 per minute. Since the T value for W-13 (0.00005 ft^2 per minute) is two to three orders of magnitude less than the other wells. the geometric mean for T was also computed without using the value for W-13. The geometric mean for all wells with the exception of W-13 is 0.0071 ft^2 per minute. Storativity values range from 0.369 10^{-5} to 28.27 10^{-5}, with a geometric mean of 4.192 10^{-5}, or 6.285 10^{-5} without the S value for W-13. Hydraulic conductivity (K) was computed by dividing T by the saturated aquifer thickness, which is assumed to be 100 feet, because there is approximately 100 feet of open hole (saturated) from which water was being drawn during the pump test. Hydraulic conductivity values range from 0.005 10^{-4} to 4.05 10^{-4} feet per minute, with a geometric mean of 0.35 10^{-4} feet per minute or 0.71 10^{-4} feet per minute without the K value for W-13. Table 4-13 contains a summary of the aquifer characteristics for drawdown data.

4.3.4.3 Recovery Data Analysis

The data from the recovery phase were analyzed using the residual-drawdown method (Theis, 1935). The data were plotted as drawdown versus log t/t'; the plots for these analyses are presented as Graphs 4-57 through 4-64. The slope of the line was used in the modified non-equilibrium equation to determine aquifer characteristics of transmissivity.

Transmissivity values calculated from recovery data range from 0.0017 ft^2 per minute to 0.0434 ft^2 per minute, with a geometric mean of 0.0087 ft^2 per minute. The hydraulic conductivity (K) was estimated from the transmissivity value divided by the saturated aquifer thickness. Hydraulic conductivity values range from 0.17 10^{-4} to 4.34 10^{-4} feet per minute, with a geometric mean of 0.87 10^{-4} feet per minute. Table 4-14 contains a summary of the aquifer characteristics for recovery data.

The high degree of uniformity noted in the calculated values for drawdown and recovery data is an indication of the reliability of these results. The results for T and K for each well, with the exception of W-13, using the different methods are all within the same order of magnitude. The mean T values for drawdown and recovery data are 0.0071 and 0.0087, which indicates that there is good correlation between the two different analysis methods.

4.3.4.4 Horizontal Hydraulic Gradients

Horizontal hydraulic gradients (I), which are represented by difference in head divided by difference in distance, were calculated for representative wells across the site. Gradients were computed by dividing the difference in groundwater elevation for upgradient and downgradient equipotential lines by the perpendicular distance between them.

For the deep bedrock wells, the gradients range from 0.024 to 0.100, with an average value of 0.064. For the shallow unconsolidated monitoring wells, the gradients range from 0.065 to 0.067, with an average of 0.066. Horizontal hydraulic gradients are summarized in Table 4-15.

Gradients were not computed for the shallow bedrock wells because a contour map could not be developed due to a lack of data. In order to obtain an approximate gradient for the anomaly at MW-14, the elevation head difference between MW-13 and MW-14 was divided by the distance between these 2 wells (note: although this is not considered to be an accurate method of computing gradient, it will provide an estimated value which can be useful for comparison). The anomaly between MW-13 and MW-14, has an approximate gradient of 0.291 and therefore is not representative of the gradient for the site.

4.3.4.5 Vertical Hydraulic Gradients

Information obtained from the nested well pairs at the site can be used to determine vertical hydraulic gradients. The vertical gradient indicates the magnitude and direction of the hydraulic head at a point in the subsurface. Hydraulic gradients are determined by: dh/dl, which represents difference in elevation head divided by difference in distance. Unlike horizontal gradients, the difference in distance, dl, represents the difference in total well depth of the screened or open interval (Freeze and Cherry, 1979). Using mean sea level as a point of reference, a negative value for vertical gradient indicates that the potential flow of groundwater is in the upward direction, and a positive value indicates a downward gradient.

Nested well pairs MW-2/MW-202, MW-3/MW-203, MW-4/MW-204, MW-7/MW-207, MW-12/W-30, MW-13/Contel, MW-14/Stout and MW-15/W-17 were evaluated for vertical gradients. Table 4-16 contains calculations for the vertical gradient for each nested well pair.

Negative vertical gradients, which indicates upward hydraulic head, were observed in well pairs MW-4/MW-204, MW-7/MW-207 and MW-14/Stout. The upward gradients were -0.0151 and -0.0022 for well pairs MW-4/MW-204 and MW-7/MW-207. MW-14/Stout had a gradient of -0.9667, which is a very high upward gradient. The remainder of the well pairs had positive gradients, indicating downward hydraulic head. The positive gradients ranged from 0.0026 to 0.0555.

The results indicate that the direction of vertical head is downward throughout the area of the nested well pairs with the exception of the anomalous area of MW-14/Stout and immediately upgradient of the wetlands. As discussed in Section 3.0 of this report, the wetlands could be a surface expression, or outcropping, of the water table. The results of the vertical gradient analysis is a strong indication that the water table has upward hydraulic head on the upgradient side of the wetlands. Although the water was approximately 9 feet below surface in MW-4 on October 14, 1992, it is possible that during a season of more precipitation the water table rises and intersects the ground surface.

4.3.4.6 Groundwater Velocity Analysis

Groundwater velocity (V_D) was calculated by multiplying the hydraulic conductivity by the average hydraulic gradient (Freeze and Cherry, 1979).

$$V_D = KI$$

This velocity represents Darcy velocity. The actual groundwater velocity (V), also known as seepage velocity or average linear velocity, equals Darcy velocity divided by porosity (n).

$$V = V_D / n \quad \text{or} \quad V = KI / n$$

Porosity equals the volume of voids divided by the total volume of solids, multiplied by 100%. Typical primary porosity values for shale range from 0 - 10 % (Driscoll, 1987). Primary porosity refers to the porosity that occurs at the pore interstices, which is part of the matrix. When the shale is very consolidated, the effective porosity is limited to that of the primary porosity and therefore can be very low. However, a fractured rock develops secondary porosity, which refers to the voids created by fractures, fissures cracks or openings. Since the shale at the site is fractured, its effective porosity (primary and secondary) will be higher than a consolidated (non-fractured) shale. Although effective porosity for shale can be as low as 0.005, effective porosity values are expected to be higher for the site based on the presence of fractures and sand layers. The bedrock wells can yield from 2 to 6 gallons per minute according to the findings of the step tests. Bedrock aquifers that have very low effective porosities (primary and secondary) commonly have very low hydraulic conductivity values. The fact that the wells yield 2 to 6 gpm and the bedrock aquifer has an average hydraulic conductivity value of 0.87 10^{-4} feet per minute, it is unlikely that appreciable water flows through the primary pores. If the flow is primarily through a fracture network and sand layers, the primary porosity of the shale will be negligible and using primary porosity values for competent shale will result in seepage velocities that are much higher than actual rates, and therefore it is inappropriate to calculate seepage velocities without representative porosity values. However, it is appropriate to note that seepage velocities will always be higher than the Darcy velocity because the value for porosity will always be less than one.

For drawdown data (Table 4-13), Darcy velocity values range from 0.058 10^{-5} to 2.59 10^{-5} feet per minute, with a geometric mean of 0.489 10^{-5} feet per minute. For recovery data (Table 4-14), Darcy velocity values range from 0.109 10^{-5} to 2.78 10^{-5} feet per minute, with a geometric mean of 0.63 10^{-5} feet per minute.

4.3.4.7 Capture Zone Analysis

The ultimate goal of performing aquifer testing is to design a groundwater recovery system that will effectively capture the contaminant plume in the deep bedrock aquifer at the site. The step tests (described in Report No. 1, Step-Drawdown Test, dated October 9, 1992) were conducted to determine the maximum sustainable pumping rate for a recovery well. The long-term pump test (described in this report) was undertaken to evaluate the hydrogeologic characteristics, namely hydraulic conductivity, at the site.

The site-specific data can be used to calculate an anticipated capture zone for recovery wells. Capture zone can be calculated by determining the downgradient stagnation point (also referred to as velocity divide) of a well pumped at any discharge rate. The distance to the downgradient stagnation point, represented by radius r, equals the discharge rate (Q) divided by the product of $2\pi hKI$, where h is the effective saturated thickness of the aquifer zone yielding water to the well, K is hydraulic conductivity, and I is hydraulic gradient (derived from Keely and Tsang, 1983). The upgradient radius of influence is determined by $2\pi r$, and the sidegradient boundary is determined by πr. Therefore, the capture zone can be illustrated as a circle of radius πr, with the pumping well located on the downgradient boundary of the circle. Thus, the pumping well has a much greater influence on the upgradient side, which is to be expected since the groundwater is flowing toward the well.

To determine the capture zone of the deep bedrock aquifer, the average hydraulic gradient of 0.064 (dimensionless), the discharge rate of 2 gallons per minute (0.27 feet^3 per minute) and an effective saturated thickness of 100 feet for the aquifer zone yielding water to the well were used in the calculations. Minimum and maximum hydraulic conductivity values (for deep wells) of 0.16 10^{-4} feet per minute to 4.34 10^{-4} feet per minute were used to calculate a range for the downgradient stagnation point (the K value of W-13 was not used because the resulting capture zone would be unrealistic and unreasonable). The capture zone radius (r), based on the foregoing values, ranges from 15.5 feet to 420 feet (downgradient stagnation point). The upgradient capture zone ranges from 97.2 feet to 2640 feet. The sidegradient capture zone ranges from 48.6 feet to 1320 feet. Using an average mean hydraulic conductivity of 0.79 10^{-4} feet per minute, the average extent of the downgradient, upgradient and sidegradient capture zone is 85 feet, 534 feet, and 267 feet, respectively.

The maximum, minimum and average calculated capture zones have been plotted on the site map to show the potential area of influence for W-30 (Parella) pumped at 2 gallons per minute (Map 4-H). It is to be noted that if the yield of W-30 is increased through proper well development, the extent of the capture zone will increase proportionally. The minimum capture zone, which covers an area of approximately 7400 square feet, does not influence the entire extent of the contaminant plume. A multiple recovery well based system would be effective in capturing the plume as long as the capture zones were hydraulically connected or overlapping.

4.3.5 Conclusions and Recommendations

The groundwater contour results indicate that the pumping of W-30 (Parella) had a major effect over a large area of the study site. The pump test created drawdown in all of the monitored wells (with the exception of the anomalous measurements from MW-14), which indicates that the bedrock aquifer and unconsolidated sediment aquifer may be hydraulically connected. This is significant in that the site has been studied as having separate aquifers, primarily a deep fractured bedrock aquifer and a shallow water table aquifer. The drawdown observed in both aquifers indicates that pumping of a well penetrating the deep aquifer potentially draws water from the unconsolidated sediments possibly through leakage.

This is confirmed through evaluation of the time-drawdown data for the pump test which indicates that the aquifer behaves similar to a leaky confined/semi-confined aquifer rather than a linear fractured bedrock. The time-drawdown data was analyzed by the Hantush-Jacob method. The curves were graphed and values were obtained for transmissivity (T) and storativity (S). The mean T obtained from the data is 0.0076 feet^2 per minute, and the mean S is 5.361 10^{-5}. From these results, a mean K value of 0.76 10^{-4} feet per minute and a mean velocity (Darcy) value of 0.489 10^{-5} feet per minute were computed.

The recovery data was analyzed by the residual-drawdown method developed by Theis. The curves were graphed and values were obtained for transmissivity: the mean T obtained from the data is 0.0098 feet^2 per minute. From these results, a mean hydraulic conductivity (K) value of 0.98 10^{-4} and a mean velocity (Darcy) value of 0.63 10^{-5} feet per minute were computed.

The mean hydraulic conductivity value for the unconsolidated aquifer (0.8669 10^{-4} feet per minute), as determined by analysis of the slug tests, is consistent with those determined by analysis of the drawdown and recovery phases of the long term pump test. The mean hydraulic conductivity values are similar, which could be an indication that the bedrock and unconsolidated aquifers are not independent. However, the fractured shale bedrock aquifer and unconsolidated till aquifer are comprised of vastly differing material, and therefore it is unlikely that the aquifers are not independent.

The maximum, minimum and average capture zones were computed and have been plotted on the site map to show the potential area of influence for W-30 (Parella) pumped at 2 gallons per minute. The minimum capture zone, which covers an area of approximately 7400 square feet, does not influence the entire extent of the contaminant plume. A multiple recovery well based system would be effective in capturing the plume as long as the capture zones were hydraulically connected or overlapping. The pattern of proposed pumping wells and their potential area of influence will be presented in the final site characterization report.

4.4 PACKER TESTS

4.4.1 Introduction

In accordance with Section 4.2.4.4 of the approved RSAMP dated April 22, 1992, packer tests were to be performed on the wells that were logged by the down hole geophysical methods. Wells MW-202, MW-203, MW-204, MW-207, W-8 (Osbourne), W-17 (Barry), W-30 (Parella), W-31 (Electra), W-32 (Stout), W-33 (Contel) and MW-12 were logged by the down hole geophysical methods.

The results of the caliper logging, the conductivity/resistivity logging and natural gamma logging were compared and correlated to determine the presence of fractures or unconformities down the profile of the wells and the possible presence of fractures carrying DNAPL or dissolved solvent.

Once these fractures and anomalies were located the wells were packed to isolate the fractures. A paired Aardvark packer system was used in conjunction with a 2" Rediflo pump installed within a 2" diameter 10' length screen set between the packers. Two 4" to 7"-diameter packers were used to isolate 10-foot sections of the bore holes that contained potential fractures identified by the geophysical logging. The pump was employed to withdraw groundwater from the fractures to stress the aquifer.

The packer tests were proposed for two reasons. First, by isolating and pumping suspected fracture zones, the yield of the potential water bearing fractures can be determined. Groundwater sampling was conducted during the packer tests to determine the nature and extent of contamination migrating through the fractures. Second, the packer test results will be evaluated to determine the nature and extent of drawdown and to determine if there is preferential drawdown as a result of interconnected fractures.

Packer tests were performed on MW-202 and W-30 during January, 1993, however due to extreme weather conditions, the completion of the remaining packer tests was delayed. The packer tests of wells MW-203, MW-207 and W-33 (Contel) were completed May 18-21, 1993. The results of the initial packer tests (MW-202 and Parella) and those recently performed (MW-203, MW-207 and Contel) indicate that packer tests do not provide reliable information regarding the characteristics of water bearing fractures in the bedrock monitoring and residential wells.

Dye will be placed in the well above the upper packer during packer testing to determine if there is downward leakage around the packer. If there is leakage, which will be identified by dye observed in the pump discharge water, the test will be stopped and no other residential wells will be tested. If there is no leakage, this process will be conducted on the remaining residential wells.

4.4.2 Packer Tests

4.4.2.1 Parella Well Packer Test

W-30 (Parella) was initially step tested and found to sustain a discharge rate of between 2 and 4 gpm, as set forth in the Step-Drawdown Test Report dated October 9, 1992. A pumping rate of more than 4 gpm during the step test caused the well to be evacuated. During the packer tests, the well was packed at intervals of 32-42 feet, 50-60 feet, 70-80 feet and 90-100 feet below grade. These intervals were pumped at discharge rates of 2 gpm, 2 gpm, 2 gpm and 1 gpm, respectively and stable water levels were achieved. Rates higher than these mentioned cause the interval to be evacuated. The sum of these pumping rates (7 gpm), over a total of 40 feet of packed well, exceed the total pumping rate for the entire well. This fact suggests that the packers are not adequately sealing the selected zone, and that leakage from above or below is affecting the flow rate of each packed zone.

4.4.2.2 MW-202 Packer Test

MW-202 was step tested and found to be unable to sustain ½ gpm, as reported in the Step-Drawdown Test Report dated April 7, 1993. During the packer tests, the well was packed at intervals of 37.8-47.8 feet, 60-70 feet, 75-85 feet and 95-105 feet below grade. All of these intervals were pumped at a discharge rate of 1 gpm and stable water levels were not achieved for any of these intervals. Since the well cannot sustain even ½ gpm, it is logical that 1 gpm would evacuate each interval. It is therefore not possible to evaluate whether the packers are not adequately sealing the selected zone, or that leakage from above or below is affecting the flow rate of each packed zone.

4.4.2.3 MW-203 Packer Test

The packer test of MW-203 was conducted on May 18-19, 1993. The well was packed at 16-28' and pumped at ½, 1, 2, 3, 4 and 5 gpm. The well was not able to sustain 5 gpm. At 50-62', the well could not sustain the lowest achievable rate of ½ gpm. At 74-86', the well pumped at ½ gpm for almost an hour before evacuating the packed zone. For the interval of 87-99', the well was pumped at ½, 1, 2, 3, 4 and 5 gpm. The well was not able to sustain 5 gpm. The step test of MW-203 showed that this well cannot sustain more than 4 gpm (see Report No. 2: Step-Drawdown Test Report dated April 7, 1993). Based on the packer test results for intervals 16-28' and 87-99', either the entire well should be able to sustain 8 gpm or there was significant leakage around the packers or through the formation. During the packer test of 87-99', dye was placed in the water in the zone above the packers. The dye was observed in the water discharged from the pump within the packers. This indicates that there is leakage occurring around the packers. Robert Marshalk, the manufacturer of the packers was contacted by Shakti to confirm that the packers were being used in accordance with design specifications. Marshalk indicated that Shakti was in fact using the packers properly and that the design of the packers would prevent water from leaking between the packers and the well hole wall. Based on this, it is apparent that the leakage is occurring through interconnected vertical and horizontal fractures in the formation.

4.4.2.4 MW-207 Packer Test

In order to confirm the conclusions drawn during the packer test of MW-203 regarding the suitability of performing packer tests, Shakti performed additional packer tests on MW-207 and W-33 (Contel). The packer test of MW-203 was conducted on May 20, 1993. The well was packed below the bottom of the steel casing at a depth of 32-44' and pumped at ½, 1, 1½, 2, 3 and 4 gpm. During the pumping of the 32-44' interval at 4 gpm, dye was placed in the water in the zone immediately above the packers. Within 7 minutes the dye was observed in the discharge water. The observation of the dye indicated that there is leakage in the well and therefore further packer testing of MW-207 would not yield useful data.

4.4.2.5 Contel Well Packer Test

As with the packer test of MW-207, the packer test of Contel was performed in order to confirm the conclusions drawn regarding the reliability of packer tests data. The packer test of W-33 (Contel) was conducted on May 21, 1993. Contel was packed below the steel casing at a depth of 62-74' and pumped at 1, 2 and 3 gpm. During the pumping of this interval at 3 gpm, dye was injected into the water in the zone immediately above the packers. Within 12 minutes the dye was observed in the discharge water. Like the packer tests of MW-203 and MW-207, the observation of the dye indicated that there is leakage through the formation and therefore no further packer testing of Contel was performed.

4.4.3 Conclusions and Recommendations

In light of the foregoing, General Switch has re-evaluated the reliability of data obtained from the packer testing. Since leakage was observed in all of the wells that were packer tested, it is apparent that packer testing does not provide data regarding the extent of fracture zones, the amount of water yielded by specific fracture zones or the concentrations of contamination travelling through the fractures.

The packer tests, although not providing data about specific fracture zones, do provide useful information regarding the overall site geology; namely, that the shale bedrock is highly fractured in both the horizontal and vertical directions. Upon review of the caliper logs of the deep residential wells, it is clear that the older residential wells are degraded. The rock cores for the deep bedrock monitoring wells were reviewed and the fracturing observed in the cores for each of the bedrock wells was in both the horizontal and vertical planes. These observations are consistent with the nature of the bedrock - it is a fissile shale that is highly fractured in many directions.

The results of the packer tests indicate that there may be vertical leakage in all of the well tested. This fact combined with the caliper log data and the rock core analysis indicates that regardless of whether the packer is able to obtain a good seal, complete isolation of the suspected fracture zone will not be possible due to vertical leakage.

In light of the foregoing, one additional conclusion that can be drawn is that groundwater flow in the bedrock is most likely through numerous minor fractures instead of several major fractures. This conclusion is supported by the evaluation of the Parella bedrock well pump test data. A radial flow method for data evaluation was employed instead of a linear flow method, which indicates that the flow is probably through numerous interconnected minor fractures and not only major fractures.

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CONTENTS

SECTION 5

5.0 EXTENT OF CONTAMINATION

This section discusses the extent of the contamination of the General Switch site in the soils, groundwater, surface water and sediments, sewer and air. The primary contaminant is considered to be PCE. This volatile organic compound was found consistently in the soil and groundwater in the Site Study Area.

5.1 SUMMARY OF EXTENT OF SOIL CONTAMINATION FROM 1983-1984

A summary of the studies conducted by the NYSDEC and Fred C. Hart is presented below. A detailed description of these studies is presented in Appendix 5-1. In December 1983, the NYSDEC conducted soil sampling and analysis at the site. The following levels of PCE were detected:

LOCATION	DEPTH (FEET)	PCE CONCENTRATION (PPM)
S. of the GS Bldg.	0-2.5	100
NW of the GS Bldg.	-----	1,000
SW of the GS Bldg.	-----	95
SW of the GS Bldg.	-----	400
Throughout 100 Radius of the GS Bldg.	-----	10

The soil gas survey conducted by Fred C. Hart indicated levels of 1,000 ppm in three areas in the parking lot as shown on Figure 5-1.

Fred C. Hart conducted a test pit investigation and the levels of PCE in the soil samples ranged from 0.009 ppm to 2,200 ppm. The levels of PCE found in each Test Pit and the associated depth are presented on Figure 5-2.

Eight soil borings were completed at the site by Fred C. Hart during the 1984 investigation. The levels of PCE detected in the soil samples collected from the borings ranged from not detected (ND) to 3.2 ppm, shown on Figure 5-3.

In an effort to further define the extent of soil contamination, Fred C. Hart conducted a second set of four test pits, TP-A through TP-D and twenty additional soil borings. The location of the test pit and borings and the identified areas of contamination are presented on Figure 5-4. The soil sample analysis results from the areas of Test Pits TP-6, TP-D and TP-A are presented in Figures 5-5 through 5-8. The on-site and laboratory analysis show that volatile organics were detected in excess of 1,000 ppm in TP-D, and TP-A, at depth of up to approximately 12 feet below grade.

In summary, the investigations in 1983-1984 indicated PCE contamination at TP-A (northeast of the General Switch building, rear) and TP-D; however, the extent of contamination had not been established.

5.2 SOIL SAMPLING IN 1992

The 1992 soil sampling program conducted by Shakti, in accordance with Section 4 of the RSAMP, was used to further establish the horizontal and vertical extent of soil that requires treatment.

Soil borings were drilled in the area of the hot spots TP-6, TP-A and TP-D to determine the extent of contamination in the unconsolidated soils on site. The volatile compounds detected are presented in the Sample Analysis Summary Table in Appendix 5.

A review of the volatile compounds reported indicate that such compounds as methylene chloride, trichloroethylene, benzene, tetrachloroethylene, toluene, chlorobenzene and ethylbenzene were present in the samples. However, in almost every sample the principal contaminant of concern at the highest concentration is tetrachloroethylene. Thus, in this initial assessment the tetrachloroethylene values only have been plotted following the logic that in the extent of contamination the worst case would be represented by the tetrachloroethylene concentrations and that, during remediation, if the tetrachloroethylene is cleaned up, the other volatiles in most cases will be removed at the same time.

In some samples acetone was detected in both the sample and the blank, indicating that the acetone, which was used in the decontamination of the sampling equipment, was not entirely removed from the cleaned sample equipment and contaminated the subsequent sample.

5.2.1 Area of TP-A

The soil type affected by the tetrachloroethylene contamination at the rear door of General Switch at TP-A (Figure 5-9) is a dense glacial till composed of silty sand with clay that contains shale fragments. The till is approximately 15 feet deep to bedrock, as shown on the cross-sections on Figures 5-10 and 5-11.

TP-A is adjacent to the back door and is approximately 20 foot wide by 60 feet long. The concentrations of tetrachloroethylene detected above 50 ppm are within 60 feet of the rear (north) door of the plant (Figure 5-12). The concentration of tetrachloroethylene in the laboratory samples taken from TP-A varied from the highest in soil boring SB-6 to non-detectable in soil boring SB-5.

Soil boring SB-6 had the highest concentration of tetrachloroethylene at 5,500 ppm, which was detected at the 2-4 foot interval from this boring. The sample collected from SB-6 at a depth of 8-10 feet contained less than 1 ppm of tetrachloroethylene. These results indicate that no significant surface contamination at this boring location migrated vertically.

The closest soil boring in area TP-A to the rear door is OB-9, which was performed approximately 10 feet of the rear door. The sample collected at 4 to 6 feet in OB-9 contained tetrachloroethylene at a concentration of 520 ppm. The sample from 10 to 12 feet, which was collected immediately above bedrock, contained concentrations of tetrachloroethylene at 51 ppm, above the 50 ppm criterion as set forth in the Consent Decree. This indicates that some tetrachloroethylene may have migrated to the bedrock.

OB-2 contained higher concentrations than those detected in the soil samples collected from OB-9. A concentration of 950 ppm was detected by the laboratory within the top 2 to 4 feet of soils in OB-2, a concentration of 490 ppm was detected at the approximate midpoint of the soil column, and 360 ppm of tetrachloroethylene was detected in the soil at the top of bedrock. Thus, the 50 ppm soil standard is exceeded in all three samples from this boring.

The soil samples from OB-6 and OB-7, which are closer to the foundation of the building, are less than 0.200 ppm, indicating that the tetrachloroethylene concentrations in excess of the 50 ppm standard are limited to area from OB-9 to SB-6 that extends TP to the bedrock. The tetrachloroethylene samples are presented in Figure 5-10 from SB-7 to OB-9.

Additional definition of this source will be limited by the width of the alley, which is only 20 feet wide, about twice the width of a drill rig. This makes maneuvering very difficult. Without the permission of Mr. Roselli (the resident adjacent to and north of the building), additional definition of the source will be restricted to the General Switch property (Industrial Place).

5.2.2 Area of TP-D

The soil samples taken from soil borings to bedrock adjacent to the rear loading dock at TP-D (Figure 5-13) and analyzed in the laboratory contained a lower concentration of tetrachloroethylene than at TP-A. Only one soil boring, SB-12 (MW-18), contained levels of tetrachloroethylene above the 50 ppm criterion concentration (Figure 5-14). At SB-12, PCE was detected at 50 ppm and 370 ppm at 6-8 feet depth and 22-24 feet (immediately above the bedrock), respectively. Thus, it appears that solvent in the area of TP-D reached the top of bedrock. In all the surrounding soil borings the concentration of tetrachloroethylene was below the 50 ppm criterion (Figures 5-14 and 5-15).

Installation of soil boring SB-24 was in addition to the requirements of the RSAMP, and was prompted by the results of the Photovac analyses. This soil boring was installed to define the extent of contamination and the means of contaminant migration between the hot spots TP-D and TP-6, the hot spot at the foot of the fill forming the General Switch parking lot. It is noted that the bedrock between SB-8 and SB-24 rises toward TP-6, making it unlikely that the solvent flowed on the top of bedrock toward the hot spot TP-6. However, the top of the glacial till slopes from the rear of the loading dock at SB-9 to SB-24 and then down into the wetlands adjacent to TP-6, indicating that the solvent may have migrated on the top of the glacial till to reach TP-6.

5.2.3 Area of TP-6

Laboratory analysis of all the samples from soil borings in area TP-6 yielded concentrations of less than 50 ppm tetrachloroethylene (see Figures 5-16 through 5-18A).

5.3 EXTENT OF GROUNDWATER CONTAMINATION

5.3.1 Summary of Previous Groundwater Investigations

5.3.1.1 Glacial Till

Eight shallow monitoring wells screened to the base of the glacial till were installed by Fred C. Hart. Seven of the eight monitoring wells screened at the base of the glacial till were sampled on October 19, 1984. The results indicate in Table 5-1 that groundwater containing 27 ppm tetrachloroethylene was detected in MW-4 and 15 ppm tetrachloroethylene was detected in MW-3. The groundwater encountered at the base of the till and the top of the Shale appears to flow to the south. These two wells are downgradient in terms of groundwater flow from the General Switch facility as indicated by the groundwater contours plotted in Figure 5-19. Analytical results of groundwater samples collected from residential wells in 1989-1990 are summarized in Table 5-2.

5.3.1.2 Shale Bedrock

From October 17, 1983 to March 16, 1984, water samples from potable wells within a one-mile radius of the General Switch plant were analyzed for tetrachloroethylene. The data generated from over 300 groundwater samples indicated that twenty wells on Highland and Watkins Avenues had detectable concentrations of tetrachloroethylene.

Seven domestic wells and one industrial well (at General Switch) contained concentrations of tetrachloroethylene that exceeded the NYSDOH 1984 maximum permissible concentration (50 ppb) for any single synthetic organic chemical. Between October 1983 and December 1983 the pattern of tetrachloroethylene contaminated above 4 ppm in the groundwater extended from well W-30 (Parella) through wells W-32 (Stout) and W-18 (Ruppert) (see Figure 2-22).

In 1984, the tetrachloroethylene contamination of wells in the Washington Heights Section of the Town of Wallkill was restricted to wells drawing water from the Austin Glen Series and not in the shallow dug wells in the area. Permeability in this formation is determined by the degree of fracturing, openness of joints and bedding planes, and the interconnection of joints. The distribution of contaminants in the area indicates transmission of the contaminants along regional fractures. Those wells that obtain the highest level of contaminant concentration are on a regional fracture that connects to the source of contamination.

As of July 1988, the nearest residences to General Switch that used the aquifer as a drinking water source were: the Perry residence that had historically been unaffected by the groundwater contamination and the Ogden (now Wood), Seeley and Gilbert residences at 319, 321 and 323 Highland Avenue. Groundwater samples from these wells in November 1983 to April 1984 indicated the wells contained 1 ppb to non-detected (ND) concentrations of tetrachloroethylene, indicating that these wells were not on a major fissure carrying the contaminants.

In November 1983 to April 1984, the residences on Watkins Avenue that were supplied from wells were Hammerquist, Wegenroth, Rassmussen, Morse, Winner, Prior King Press, Cosmo Optics, Radivoy, Campbell, Jehovah Witness, Wand and Saxton. All the other residences on Watkins Avenue were supplied with municipal water from Middletown. In November 1983 to April 1984 all the wells on Watkins Avenue were free from tetrachloroethylene contamination except Prior King Press (ND, 2 and 3 ppb), Winner (ND and 1.1 ppb), W-19 (Rassmussen) (12 ppb and ND), Morse (4 ppb and ND) and W-22 (Wand) (2 ppb and ND).

All the wells tested in 1983-1984 on Commonwealth Avenue were less than 1 ppb or non-detected for tetrachloroethylene.

Water well testing was conducted by Hart between June and September 1984. The results of potable water analysis, presented in Appendix 5 and in depicted in Figures 5-20 through 5-22, indicate the same pattern established by the prior USEPA testing. Based on the results of potable water well sampling, the orientation of the plume remained fairly stable in a northwest to southeast configuration since contamination was first found in October 1983 through to September 1984. This orientation is approximately parallel to the direction of the shallow trough located under the General Switch property (Industrial Place). The trough may be evidence of a large-scale fracture pattern that is channeling movement of the tetrachloroethylene contaminant plume.

During the four months of sampling by Hart, the most contaminated wells encountered were at the properties of Ruppert (307 Highland Avenue), Liska (304 Highland Avenue), Barry (309 Highland Avenue), Stout (316 Highland Avenue), Parella (320 Highland Avenue), General Switch (Industrial Place) and Lewis (313 Highland Avenue). With the exception of Liska and W-16 (Lewis), all the other wells had previously been identified as contaminated with over 50 ppb of tetrachloroethylene. The outer limit of the plume between January and June 1984 extended to the wells of Schmick, Eckerson to the south of Highland Avenue, Rassmussen and Winner on the south of Watkins Avenue, Van Pelt, Seeley and Fiore mid-way along Highland Avenue. The plume extended westward at Prior King Press and Cosmo Optics on Watkins Avenue. In addition, the plume extended northward to the wells of Ernest, Pitt and Schmall on Highland Avenue and encompassed the abandoned General Switch supply well.

Tetrachloroethylene concentrations in excess of 50 ppb were first noticed in the W-16 (Lewis) and Liska wells sampled on July 17, 1984. Another set of samples was taken on August 28, 1984, to confirm the previous results. This increase in these wells downgradient in terms of groundwater flow from well W-30 (Parella) occurred after the Parella (320 Highland Avenue) and Stout (316 Highland Avenue) residences were provided with city water and ceased to pump their wells. All the other wells in the General Switch vicinity remained uncontaminated.

In general, the concentrations and distribution of tetrachloroethylene had changed very little since USEPA's last samples were taken in March 1984. The trend of tetrachloroethylene distribution had remained in a northeast-southwest orientation and the contamination found in the Liska and W-16 (Lewis) wells conformed to this pattern.

Figures 5-23 and 5-24 show the piezometric surface of the bedrock aquifer. The additional data from the Technical Assistance Team and Hart studies fills a gap in the knowledge of the hydrogeology of the area and the nature and extent of groundwater contamination in the shale in the period 1983-84.

The survey of the water quality in wells adjacent to General Switch was continued. Well W-13 (Wood), identified in August 1989 as being used for private supply, was sampled on August 17, 1989 along with other neighboring wells of households, such as W-32 (Stout), on city water. The results of the 1989-1990 analyses are summarized in Appendix 5. A brief summary is presented in Table 5-2.

5.3.2 Groundwater Investigations in 1992

The review of the groundwater quality data from the General Switch property (Industrial Place) and surrounding properties demonstrated that the highest concentration of tetrachloroethylene found in the shale aquifer is in the area of well W-30 (Parella). Based on this information, it is apparent that well W-30 (Parella) may be the principal well to choose as the pumping well for plume capture and remediation. The 3-day pump test, which is described in Section 4 of this Report, was conducted to evaluate the suitability of well W-30 (Parella) for groundwater extraction and plume capture. Groundwater sampling was performed before and after the 3-day pump test to determine if limited pumping had any measurable effects on the contaminant concentrations in wells surrounding well W-30 (Parella).

5.3.2.1 Groundwater Sampling

Groundwater sampling was completed as proposed in the RSAMP. Groundwater samples were collected from the monitoring wells and the residential wells adjacent to General Switch prior to the 3-day pump test and a minimum of 2 weeks following the development of each new monitoring well.

During groundwater sampling, the groundwater was screened with a Photovac 10S50 that was calibrated for the specific volatile compounds at this site. The Photovac is capable of achieving detection limits of 10 ppb.

5.3.2.2 First Round of Groundwater Sampling

Groundwater samples were obtained from residential supply and monitoring wells in the first round of groundwater samples from September 15 to October 13, 1992.

The analytical results for tetrachloroethylene in all of the monitoring and residential wells sampled are included in Appendix 5 and shown on Maps 5-2 through 5-7 in Appendix 5.

5.3.2.3 Glacial Till - First Round

The extent of contamination in the glacial till is determined by the groundwater sample results for those wells screened in the glacial till to the top of bedrock.

The highest concentration of tetrachloroethylene in the groundwater at the base of the glacial till was detected in well MW-5 at the toe of the slope of the General Switch parking lot adjacent to the wetlands. A concentration of 41,000 ppb of tetrachloroethylene was detected in the laboratory sample, which is above the groundwater criterion noted in the Consent Decree. Well MW-5 contained very little water and was in fact dry during the second round of groundwater sampling. The concentration of tetrachloroethylene in the groundwater below TP-6 was detected in well MW-16 at 8,300 ppb.

The concentration of tetrachloroethylene in the groundwater decreases downgradient in the direction of groundwater flow into the wetlands from MW-5 to MW-4 with a concentration of 20,000 ppb of tetrachloroethylene to a concentration of 27 ppb tetrachloroethylene at MW-6. Well MW-9 in the wetlands was not able to be installed prior to the first or second round of groundwater samples but was subsequently sampled in May of 1993.

The concentration of tetrachloroethylene in the groundwater in TP-A (rear door of the General Switch building) was detected in well MW-17 at 1,200 ppb during the first round of groundwater samples.

Upgradient well MW-8 and MW-11 were dry during the first round of groundwater samples, defining the upgradient extent of any groundwater perched above the till.

It appeared that the source of the groundwater contamination in the glacial till in the wetlands originated from either TP-D or TP-6 as seepage at the base of the glacial till at or about MW-3 and MW-5.

5.3.2.4 Top of Bedrock - First Round

Four wells were installed in the top of bedrock along Highland Avenue adjacent to the deep wells of the Parella (320 Highland Avenue), Stout (316 Highland Avenue), Contel (306-314 Highland Avenue) and Ruppert (307 Highland Avenue) properties, as shown on Map 5-3, Appendix 5. The shallow rock wells were installed close to those deep bedrock residential wells that had shown PCE contamination to determine the impact of the solvent spill on the top of bedrock in these areas. The concentration shows a consistent decrease downgradient from the site from 140 ppb tetrachloroethylene in MW-12 on the Parella property (320 Highland Avenue) to 130 ppb in MW-13 (Stout), 12 ppb in MW-14 (Contel) to 4 ppb at MW-15 (Barry) lot.

5.3.2.5 Bedrock Aquifer - First Round

Groundwater samples were obtained from four monitoring wells and 17 residential wells that have been drilled with casing through the glacial till and open hole to a depth of at least 100 feet to monitor the groundwater quality in the bedrock aquifer. The concentrations of tetrachloroethylene in the bedrock aquifer are presented in Map 5-4, Appendix 5.

The upgradient monitoring wells were W-1 (Perez) and W-36 (Radivoy). No tetrachloroethylene was detected in these residential wells.

The highest concentration of tetrachloroethylene in the first sample round was noted in well W-30 (Parella) at 150,000 ppb, in W-32 (Stout) at 1,100 ppb and in wells W-17 and W-18 (Barry and Ruppert) at 3,100 ppb and 8,200 ppb. The elongated pattern of the contours of concentration extended in an east-west direction, indicating a preferential flow pattern following a regional fracture oriented close to these wells.

It is remarkable that many wells close to these contaminated wells that have significant groundwater contamination in the shale bedrock contain only a trace amount of or no tetrachloroethylene, and that these relatively clean wells are encircled by contaminated wells, thereby defining the extent of groundwater contamination in the shale. Thus, the two wells immediately downgradient of well W-18 (Ruppert), well W-19 (Rassmussen) and well W-37 (Holmes) on Watkins Avenue, contained no tetrachloroethylene. The downgradient well W-34 (Petruzzio) on Highland Avenue was free of any tetrachloroethylene contamination. The wells on the north side of Highland Avenue adjacent to the plume include wells W-14 (Knapp) (3.7 ppb tetrachloroethylene) and W-15 (Van Pelt) (no contamination), along with W-11 (Gilbert), W-13 (Ogden) and W-7 (Cornelius). Well W-8 (Osbourne) has a history of groundwater contamination, as reported in the RSAMP, and contained 9 ppb tetrachloroethylene in this sample round. Well W-26 (Radivoy), located on the hill overlooking Highland Avenue, was also free of tetrachloroethylene.

5.3.2.6 Second Round of Groundwater Sampling

Following the pump test of well W-30 (Parella), a second round of groundwater samples was obtained from the monitoring and residential wells.

5.3.2.7 Glacial Till - Second Round

The pattern noted in the first round of groundwater samples was repeated in the second round of samples except that the concentrations of tetrachloroethylene were slightly higher in the glacial till in the second round (Map 5-5 in Appendix 5).

Well MW-5 was dry in the second sample round. Well VES-2, installed through the hot spot TP-D, contained 21,000 ppb tetrachloroethylene under this zone of soil contamination. MW-3, under the hot spot TP-6, contained groundwater with 11,000 ppb tetrachloroethylene at the toe of the slope from the parking lot. Significant and more elevated concentrations of tetrachloroethylene were detected in the wetlands. Well MW-4 contained 26,000 ppb in the second round: an increase from the 20,000 ppb of the first round of sampling. Apart from these significantly contaminated wells screened to the base of the glacial till, the other wells downgradient from hot spot TP-6, MW-7 and MW-6, contained tetrachloroethylene concentrations of 120 and 34 ppb, respectively. Monitoring well MW-9, 600 feet south of the General Switch building, was sampled on May 28, 1993, after the completion of the second round of groundwater sampling. Laboratory analysis indicated a tetrachloroethylene level of 2,700 ppb. The upgradient well MW-8 was dry and MW-1 on the hillside above General Switch contained 10 ppb tetrachloroethylene. The results of the analysis for MW-2, 11 ppb tetrachloroethylene, above the plume of groundwater contamination in the bedrock indicated that the plume was not pulled up into the top of the bedrock in any significant concentration by pumping and sampling this nested bedrock well.

5.3.2.8 Top of Bedrock - Second Round

The four wells in the top of bedrock along Highland Avenue were sampled again in the second round (5-6, Appendix 5). Tetrachloroethylene concentrations decreased downgradient from 280 ppb at MW-12 on the Parella Property (320 Highland Avenue) to 18 ppb at MW-15 at the Barry property (309 Highland Avenue), with the exception that MW-13 contained 2,900 ppb tetrachloroethylene; that may be the result of cross-contamination from the demonstrated groundwater plume in the bedrock of between 3,100 ppb and 3,700 ppb in the area of well W-33 (Contel) and W-30 (Parella), respectively.

5.3.2.9 Bedrock Aquifer - Second Round

In the second round of groundwater samples, the upgradient residential well W-1 (Perez) showed an increase in tetrachloroethylene concentration from non-detected to 4.9 ppb (Map 5-7, Appendix 5).

In the second round of groundwater samples in the bedrock, the same pattern of wells with tetrachloroethylene contamination was noted in well W-30 (Parella) at 3,700 ppb, and in well W-17 (Barry) at 1,800 ppb. However, the tetrachloroethylene levels in the contaminated wells had decreased by as much as one order of magnitude when compared to the first sample round. The concentration noted in well W-30 (Parella) was significantly reduced to 3,700 ppb from the 150,000 ppb concentration detected in the first sample round. Well MW-202 significantly increased in concentration from 240 ppb to 9,600 ppb following the 3-day pump test of well W-30 (Parella). Similarly, the concentration of tetrachloroethylene in well W-33 (Contel) increased from 420 ppb in the first round to 3,100 ppb in the second round.

A significant reduction was noted in W-32 (Stout) from 1,100 ppb to 160 ppb and in well W-17 (Barry) from 2,700 ppb to 130 ppb. The elongated pattern of the concentration contours in an east-west direction was still noted, indicating a preferential flow pattern following a regional fracture oriented close to these wells.

The residential supply wells that were free of any tetrachloroethylene at well W-18 (Ruppert), downgradient of the plume, W-34 (Petruzzio), W-38 (Nixdorf), W-26 (Robaina), W-19 (Rassmussen) and W-37 (Holmes). The extent of the plume in the bedrock was defined by the residential wells on the north side of Highland Avenue that did not contain any tetrachloroethylene including W-14 (Knapp), W-15 (Van Pelt), W-11 (Gilbert), W-8 (Osbourne) and W-7 (Cornelius).

The contamination noted in MW-4 (screened in the glacial till) of 20,000 ppb tetrachloroethylene was not as yet, reflected in similar concentrations in the underlying bedrock in the nested well MW-204 that contained 204 ppb tetrachloroethylene.

5.3.2.10 Bladder Pump Sampling

Bladder pump sampling was performed as proposed in Sections 4.2.4.3 and 6.6.4 of the RSAMP. According to the RSAMP, in order to obtain information on the presence of fractures and any DNAPL carried through the fractures, sampling was to be performed with a Marschalk bladder pump in select wells at 20-foot intervals down the profile of the wells or at potential contamination bearing zones. Potential contamination-bearing zones were identified through interpretation of the downhole and geophysics logging and were targeted for sampling. Wells W-30 (Parella), W-32 (Stout), W-17 (Barry), W-18 (Ruppert), W-8 (Osbourne), W-1 (Perez) and W-33 (Contel) were sampled at 20 foot intervals due to the lack of geophysics data.

Bladder pump sampling was performed on wells W-30 (Parella), W-32 (Stout), W-33 (Contel), W-17 (Barry), W-18 (Ruppert), W-8 (Osbourne), W-1 (Perez), W-31 (Electra) and on monitoring wells MW-202, MW-203 and MW-207. A discrete sample was obtained from each interval and analyzed in the field for PCE utilizing the Photovac 10S50 gas chromatograph. Duplicate samples from zones of high ground water contamination and from the base of the residential wells were analyzed for VO+10 by Method 624/524.2 in the CLP laboratory. In total, at least 10% of the bladder samples were submitted for laboratory analysis.

No free product was noted in the base of wells W-30 (Parella), W-8 (Osbourne), W-18 (Ruppert), W-32 (Stout) or W-17 (Barry). Although not required in the RSAMP, bladder sampling of well W-1 (Perez) was conducted in order to identify any fractures in well W-1 (Perez) upgradient from the General Switch site.

The intervals bladder sampled along with the Photovac and confirmatory laboratory results are summarized in Table 5-3, PCE Bladder Pump Sampling Results. Some of the Photovac results are estimated values based on the response of the peak. If the temperature of the sample varied, the retention time of PCE would be altered and the Photovac would identify PCE as an unknown compound. The concentration would then be estimated by the Photovac operator by the area of the peak. Although there is a great degree of uncertainty in these estimated concentrations, the estimates are useful in determining approximate concentrations.

Bladder pump sampling indicated the presence of tetrachloroethylene contamination in all of the wells with the exception W-1 (Perez), which is upgradient of the site. The most contaminated wells are MW-202, MW-203, MW-207, W-18 (Ruppert), W-30 (Parella) and W-33 (Contel); lesser contaminated wells include W-17 (Barry), W-8 (Osbourne), W-31 (Electra) and W-32 (Stout) residential wells. Well W-1 (Perez) was clean.

In most of the wells sampled, the bladder pump sampling did not define any one zone of high tetrachloroethylene contaminated groundwater. Most of the Photovac results for each well were either within the same or one order of magnitude. The highest degrees of variation in the Photovac results were detected in well W-17 (Barry), which ranged from 24.6 to 1,430 ppb, and well W-30 (Parella), which ranged from 70.15 to approximately 10,000 ppb.

The bladder sampling did not define zones of high contamination for two potential reasons. First, it is possible that the PCE is uniformly distributed throughout the aquifer which was reflected in the sample results. This is unlikely given the sinking (DNAPL) nature of PCE and the presence of a highly fractured bedrock. The second reason is that the bladder pump was ineffective at drawing groundwater from the actual aquifer. The water that was analyzed may have been drawn from the water column in the borehole of the well and not from the formation. It is probable that the contaminant concentration in the water in the well borehole reaches equilibrium due to diffusion and dispersion.

5.4 SEWER SURVEY AND SAMPLING

A sewer survey and sampling program, as proposed in the RSAMP, was performed. Water and sediment samples were collected in the sanitary and industrial sewer line along Industrial Place and Industrial Place Extension at the locations shown on Figure 5-25, PCE Concentrations in Surface Water and Sewer Samples. Laboratory results are summarized in Table 5-4.

Manholes were located at the intersection of Highland and Park Avenues, the intersection of Highland Avenue and Industrial Place, on Industrial Place adjacent to General Switch receiving a contribution from the plant, at the right angle corner and intersection of Industrial Place and Industrial Place Extension, and adjacent to and downstream of the Lubricants, Inc. process sewer line.

The General Switch lateral servicing the plant discharges into the City of Middletown Sewage Treatment Plant. The rest of the industrial customers along Industrial Place Extension also discharge to this same sewer line for treatment by the City of Middletown Sewage Treatment Plant. At the time of this inspection, the sewer manholes were accessible for sampling. The sewer lines appeared to be in good condition with no sediment present and little debris clogging the lines.

At the end of July, the City of Middletown repaved Industrial Place and Industrial Place Extension. The manholes designated for sewer water and sediment sampling were covered with fresh paving. In order to complete the proposed sampling, a metal detector was employed to locate the manholes to permit access to the sewer lines.

On December 9, 1992, the sewer water and sediment samples were collected according to the standard operating procedures presented in Section 6.0 of the RSAMP. The sewer water samples were analyzed for volatile organics by Method 624 and the sediments by Method SW846/8240.

The manholes were successfully located and uncovered prior to sampling, except for the manhole adjacent to Wallace Oil, the manhole at the intersection of Highland Avenue and Industrial Place, and the manhole adjacent to Guild Molders. These manholes could not be found despite two separate attempts to locate them with a metal detector.

During sampling, it was observed that there was no sediment build-up in the sewer lines, except for the sewer line at the intersection of the General Switch outfall into the Middletown sewer line.

Based on the laboratory analysis of sewer water and sediment samples, tetrachloroethylene is present in both the water and sediments running through the sewer line connected to the City of Middletown Sewage Treatment Plant. Since tetrachloroethylene is a commonly used solvent, the source or sources of tetrachloroethylene could potentially be any of the industrial customers discharging to this line over the course of their operating history.

With the cessation of operations at the General Switch plant, it is difficult to assess historically the amount of tetrachloroethylene that may have been contributed by this particular operation. If we assume General Switch to be the only source of tetrachloroethylene contamination in the sewer line, then we might expect a gradual decrease of concentrations along the length of the sewer line. The deposition of sediments is affected by flow rates and quantities, the geometry and configuration of the sewer, and the condition of the pipe itself. There is a possibility that some pockets of sediments with high concentrations of tetrachloroethylene could exist in the sewer line. However, dilution and attenuation of these hot spots would be expected to occur over time, thereby reducing or eliminating the PCE.

Based on the reduction of tetrachloroethylene concentrations in the water samples taken from the sewer line at General Switch (SEW-01) to the corner of Industrial Place (SEW-02), it is reasonable to speculate that this decrease may indeed be due to attenuation, degradation and dilution over time.

The increase in tetrachloroethylene concentrations at particular junctions in the sewer line could represent accumulations over time or it could represent an additional contribution by a facility connected to the line at this point. Based on the increase of tetrachloroethylene concentrations at the manhole located 40 feet south of Lubricants, Inc. (SEW-04), it is probable that there is one or more sources on Industrial Place Extension that are contributing to the concentrations of tetrachloroethylene in the sewer line along Industrial Place Extension.

The sample (SEW-03) taken at the intersection of Highland Avenue and Park Avenue did not contain any detectable concentrations of tetrachloroethylene. This line is not connected to any of the industries along Industrial Place and Industrial Place Extension.

5.5 WETLANDS SURFACE WATER AND SEDIMENT SURVEY AND SAMPLING

The wetlands surface water and soil survey and sampling program, which is outlined in Sections 4.8.1 and 6.8 of the RSAMP, was performed. Four water samples, which could not be collected, were proposed for the locations specified in the RSAMP. Two grab samples of surface water, to be designated WET-001 and WET-002, were to be collected on the northwest perimeter of the wetlands adjacent to the study area to identify any contamination in the surface water to the south of General Switch. Two grab samples of groundwater were to be collected at WET-003 and WET-004 in order to determine if the potential exists for upwelling of contaminated groundwater into the low swampy area. The water samples were to be analyzed for volatile organics by Method 624.

On September 8, 1992, an inspection of the wetlands area was conducted. At that time, there was no evidence of any surface water, and the only surface water present was confined to a small area adjacent to the National Guard Compound along Industrial Place Extension. Apparently, this wetlands area is intermittently wet depending upon the season and the amount of precipitation occurring in the area. The amount of surface area covered by standing water would be dependent upon the length and duration of precipitation events and the permeability of the overlying soils.

According to the RSAMP, surface water samples were to be obtained at the base of the slope below the General Switch (Industrial Place) and Parella (320 Highland Avenue) properties, adjacent to Industrial Place Extension as shown in Figure 4-11 of the RSAMP. With the permission of USEPA, it was decided to collect only the two sediment samples from locations WET-003 and WET-004 in the wetlands area at that time. There would be no surface water sampling required at that time due to the lack of standing water in the wetlands area. Although the surface water sampling could not be performed as proposed in Section 4.8.1 of the RSAMP, groundwater samples have been collected from shallow monitoring wells MW-6 and MW-9, which are located in the wetlands. The groundwater sampling of these wells is contained in the groundwater section of this Report.

On September 18, 1992, two wetland sediment samples, designated as WET-003 and WET-004, were collected from the wetlands area adjacent to the National Guard Compound and along Industrial Place Extension. These samples were submitted to NYTEST laboratories for TCL Volatile Organic analysis by Method SW846/8240. Laboratory analysis indicated that sample WET-003 (Sample No. 1408617) contained no detectable levels of tetrachloroethylene. Sample WET-004 (Sample No. 1408616) contained 98 ppb of tetrachloroethylene. The locations of the wetland samples are depicted on Figure 5-25 along with the laboratory results.

Photovac results from SB-20 indicate levels of tetrachloroethylene ranging from 376 to 743 ppb in the upper layers of unconsolidated soils from the surface to 8 feet depth. Laboratory analysis of samples from SB-20 at 4-6 feet depth were non-detectable for tetrachloroethylene and the sample from 6-8 feet depth contained 100 ppb of tetrachloroethylene. At a depth of 10 feet to a depth of 12 feet, where bedrock was encountered, the concentrations increased from 1.0 to 1.3 ppm. SB-20/MW-9 was not completed until December 15, 1992, because of issues regarding wetlands access and site work. Therefore, groundwater samples were not taken from MW-9 during the Round 1 or Round 2 sampling events, but were subsequently collected in May 1993.

The presence of tetrachloroethylene in sediment sample WET-004 obtained from the wetlands, coupled with its presence in the samples obtained from SB-20/MW-9, indicates the existence of tetrachloroethylene in the unconsolidated soils above the bedrock. There are seasonal fluctuations in the surface water and groundwater levels in the wetlands which relate to factors such as the amount of precipitation, evaporation and uptake by flora. The tetrachloroethylene in the wetlands soil is most likely deposited by the fluctuation of contaminated groundwater. It is unlikely that tetrachloroethylene migrated any significant distance across the surface of the wetlands or was spilled in remote locations by General Switch.

In addition, a significant amount of trash has been dumped in the wooded and wetland areas adjacent to Industrial Place Extension. Furniture, automobile parts, car batteries, oil cans, beer bottles, mattresses and other solid waste litter the area. There is also a network of trails throughout this area connecting Industrial Place Extension with Highland Avenue, most likely used by youths and workers in this area as a short cut. While not likely, there is always the possibility of environmental impact in the immediate area from these sources.

SECTION 6

CONTENTS

6.0 PILOT STUDIES

This section presents the pilot studies which were conducted at the site: the product recovery pump, the soil vapor extraction investigation and the operation of the progressive air stripper which was used to treat contaminated water generated during groundwater activities.

6.1 FREE PRODUCT (DNAPL) RECOVERY

Free product was detected in the bottom of deep bedrock well W-30. Free product can cause significant aquifer degradation as one gallon of free product has the capacity to contaminate 200 million gallons of fresh water. Therefore, upon detection of free product in well W-30, a free-product recovery system was immediately installed. The detailed description of the system is contained in Section 2.0 of this report.

The free product recovery pump has removed approximately 10 gallons of a free product-water mixture. The system was monitored in early June, 1993 and no product had been recovered since the previous monthly inspection. The recovery system will remain in well W-30, in the event that additional slugs of product accumulate in the well, which is expected once groundwater drawdown is instituted.

6.2 SOIL VAPOR EXTRACTION INVESTIGATION

The hot spot TP-A in the rear (north) of the General Switch site building, as shown on Figure 6-1, was selected to investigate the feasibility of soil vapor extraction. The objective of this investigation was to determine if the volatile organic contaminants can be successfully removed by drawing a vacuum on the soil and providing sufficient air flow through the soil to mobilize and capture the soil vapor. The dense, consolidated glacial till and non-homogeneous overburden indicated potential limitations imposed upon the effectiveness of the available treatment alternatives for the site. The study area is approximately 20 feet wide and 60 feet long.

The soil vapor extraction investigation was attempted on October 7, 1992 through October 9, 1992; however, it was terminated prematurely due to heavy rain conditions which blanketed the investigation area with several inches of rain. In addition, an evaluation of the limited data generated in October revealed that it was not reliable. Consequently, the soil vapor extraction pilot study was rescheduled and conducted in May 1993. The investigation began at 9:26 on May 27, 1993 and was terminated at 12:44 on May 29, 1993. Dewatering was conducted prior to and during the VES Pilot Study; the water table was lowered by at least two feet in the study area.

6.2.1 Vapor-Extraction and Observation Wells

The vapor extraction well, VES-1, and a series of seven observation wells, OB-1 through OB-3 and OB-6 through OB-9, were installed in the area of the hot spot TP-A as shown on Figure 6-1. A vacuum was drawn on VES-1 and the pressure drop was monitored in the observation wells and in groundwater monitoring well MW-17. A summary of the well specifications and their distance from the vacuum extraction well VES-1 is presented in Table 6-1.

The vapor extraction well and the observation wells were constructed with a 4-inch-diameter PVC well screen and casing. The vapor extraction well logs are discussed in Section 2 of this report and are presented in Appendix 2-C.

6.2.2 Soil Vapor Recovery System Set-Up and Operation

The soil vapor extraction system schematic is shown on Figure 6-2. The vacuum pump consisted of a 7-horsepower Rotron regenerative vacuum blower capable of drawing 200 cubic feet per minute (CFM) at 22 inches of mercury. A thermistor on the unit measured extracted gas temperature. Ball and gate valves were used to control air flows and an added air vent was utilized to bleed in ambient air to cool and lubricate the blower and to control vacuum pressure on the pumped well. The blower was connected to the vapor extraction well. The air flow response for the extraction well under various vacuum conditions was determined by performing the test as a step test. The vacuum was increased from 2 inches of mercury to 4, 6, 8, 10 and 12 inches of mercury.

A moisture separator was installed in between the blower and the vacuum extraction well in order to prevent condensed soil moisture from reaching the blower. The extracted soil vapor from the blower was connected to a carbon adsorption system consisting of two sets of granular activated carbon drums prior to discharge to minimize emissions to the atmosphere. One set of carbon drums (approximately 800 pounds of carbon) was used during the survey. There was no carbon break-through.

The withdrawal of soil vapor from the vapor extraction well VES-1 induced a vacuum gradient in the subsoil which was measured by magnetohelic gauges fitted on the observation wells. Each observation well was fitted with a dedicated gauge in order to avoid having to move the gauges from well to well. The sensitivity limit of the magnetohelic gauges varied depending upon the range of pressure measured by the gauge.

To evaluate the effectiveness of the vapor extraction system, field measurements were made. The recorded measurements are presented on Table 6-2. The influent air velocity in feet per minute (FPM) represents the soil gas removed from VES-1 through a 4-inch-diameter pipe. The effluent air velocity in FPM represents the air velocity of the off-gas through a four inch diameter pipe following carbon treatment as shown on flow diagram, Figure 6-3. The ambient air velocity represents the air velocity through a 4-inch-diameter pipe. The flow measurements were made utilizing Kurz series 490 mini-anemometers with two ranges: 0 to 2,000 feet per minute and 0 to 10,000 feet per minute. The anemometers were dedicated and sealed at each location in order to minimize system leaks and obtain consistent readings.

6.2.3 Soil Vapor Extraction Survey Results

The relationship between the flow rate of the soil vapor withdrawal and the induced vacuum observed at the vapor extraction and observation wells will determine if an effective soil vapor extraction system can be utilized at the site.

The flow rates have been calculated in cubic feet per minute (CFM) at each measuring point: the influent (extracted soil vapor), the midpoint ambient air, and the effluent (following carbon treatment). In order to establish the validity of the data, a flow mass balance was conducted. As is indicated on Table 6-3, the flows are consistent and the off-gas measured flow rate compares favorably to the flow measured at the VES added to the flow of the introduced ambient air. Therefore, the data appears valid and is evaluated further.

A minimum induced vacuum of 0.1 inches of water (i.w.) is required to effect soil vapor extraction, as indicated in the USEPA Soil Vapor Extraction Technology Handbook. The maximum effective radius of influence (MERI) associated with a specific flow rate is an essential aspect in determining an optimum soil venting system. The distance from an active vapor extraction well at which the vacuum in the subsurface is 0.1 i.w. defines the MERI and determines the optimum spacing of vacuum extraction wells on a grid through the area of contaminated soil.

The MERI associated with a particular flow rate is determined empirically from the pilot test data by plotting the logarithm of the observed induced vacuum measured in the observation wells versus the radial distance form the active vapor extraction well. For each of the flow rates during the test, the plot of the log of induced vacuum [Log (i.w.)] against radial distance from the extraction well VES-1 (feet) produced a straight line graph developed by a linear regression program. The point (A) at which the line intersects the -1 logarithm value that corresponds to 0.1 i.w. is the MERI. The plots are presented in Figures 6-4A through 6-4F.

The flow rate (CFM) was then plotted against the maximum effective radius of influence (MERI, feet) and the point indicated on Figure 6-5 on the curve at which the flow rate increases exponentially corresponds to the point at which the vacuum efficiency decreases due to vacuum dissipation by increased induced flow rate in the soil. At this point the selection of optimum soil vapor withdrawal rate (B=24 CFM) and a MERI spacing of the extraction wells (C=20 feet) was determined. This corresponds to a vacuum step at 6 inches of mercury.

6.2.4 Sample Collection and Analysis

Samples were collected in the study area to obtain the levels of volatile organic contaminants in the soil. Soil samples were collected during to the installation of the VES-1 observation wells and soil boring. The samples were field screened with the Photovac 10S50 for volatile organics. The most highly contaminated soil sample from each boring was submitted to the CLP laboratory for analysis. The laboratory analysis results indicate that the highest levels of tetrachloroethylene were present in soils at SB-6; sample results from SB-6 ranged from 1 ppm (8-10 feet below grade) to 5,500 ppm (2 to 4 feet below grade). OB-2 was the boring with the next highest concentration. A concentration of 950 ppm was detected at 2-4 feet at OB-2, and a concentration of 360 ppm at 8-10 feet (bedrock) below grade.

Air samples were collected during the pilot study in order to measure the volatile organic concentration of air withdrawn from the vapor extraction well and the effluent following treatment. The samples were collected at the following locations as shown on Figure 6-3:

- VES-1 well
- Following the blower before carbon treatment
- Treated off-gas following the carbon

Samples were analyzed in the field with the Photovac and samples were submitted to the laboratory for analysis. In order to eliminate problems associated with sampling from the vacuum piping, the Gillian air sampling pump was used to collect air samples from the pressure line from the vacuum blower. For the samples which were submitted to the laboratory, the Gillian air sampling pump was calibrated and a Tenex tube, set screw (to adjust flow rate of through the sample tubing), and rotometer was set up in series. The Tenex adsorption tube was utilized to collect the sample with a Gillian air pump set at 50 and 25 milliliters per minute (ml/m) and was run for two hours. Since the samples were collected on the pressure side of the blower, the results will be diluted due to the ambient air that was bled in on the vacuum side.

The Photovac was calibrated with a standard of 50 ppm tetrachloroethylene. The analysis results of the effluent are summarized on Table 6-4. The volatile organic readings collected with a Microtip analyzer to cross-check the Photovac results are summarized in Table 6-5. The Photovac analysis printouts are presented in Appendix 6. The Photovac results indicate that the PCE concentration in the soil vapor extracted ranged from 96.1 ppm to 1,293 ppm. The Microtip PID screening results indicate that PCE concentrations in the soil vapor extracted ranged from 740 ppm to 1,887 ppm. The laboratory analysis results were not available as of the date of this report.

The PCE concentration for the sample which was collected after the VES blower is diluted by the introduction of ambient air. Further, Microtip readings were not collected at the VES since the instrument could not overcome the vacuum at VES and the levels at VES have been extrapolated from the readings after the blower.

On reviewing the data generated by the Photovac, it is apparent that the concentrations obtained from the sample at VES-1 are less than expected when compared to those obtained at the sampling point following the blower (diluted with ambient air). It appears that, although the samples were collected with a syringe through a septum into the sampling part of VES-1, leakage and dilution must have occurred due to the vacuum.

6.2.5 Removal Rates

Removal rates in kilograms per day were calculated utilizing the extrapolated volatile organic concentrations at VES-1 recorded with the Microtip and the PCE concentrations detected at VES-1 with the Photovac. The following formula (Johnson et al.) was used:

$$R = CQ$$

where:

R = Removal Rate in kg/day
C = Concentration in mg/m^3
Q = Flow rate in CFM

For the extrapolated concentration of 1,437 ppm at a flow rate of 24 CFM, the removal rate is calculated as 9.29 kg/day. For the PCE concentration of 317 ppm at a flow rate of 38 CFM, the removal rate is calculated as 3.24 kg/day. For example:

$$R = CQ$$

where:

C = 1,437 ppm = 9,771 mg/m^3
Q = 24 ft^3/min

$$R = 9{,}771\ \frac{mg}{m^3} \times \frac{1\ kg}{10^6\ mg} \times \frac{0.028\ m^3}{ft^3} \cdot \frac{24\ ft^3}{min} \times 1{,}440\ \frac{min}{day} = 9.29\ kg/day$$

Generally, removal rates of less than 1 kg/day are not acceptable for the design and implementation of vapor extraction (Johnson, et al.). Since the removal rates calculated are above 1 kg/day, it appears that they are acceptable and soil vapor extraction is feasible at the site for unsaturated soils.

6.2.6 Conclusions

An assessment of the data generated during this pilot study indicates that soil vapor extraction is a viable remedial option at the study area. However, extensive dewatering is required to lower the water table to the vertical extent of soil contamination, i.e., to the top of bedrock.

6.3 AIR INVESTIGATION

Contaminated groundwater generated during groundwater-related activities, such as well development and well purging, and groundwater from the 3-day pump test of W-30 and vapor extraction test, was treated by the progressive air stripper deployed on site.

Groundwater for treatment was first stored in a storage tank adjacent to the stripper. The tank acted as an equalization tank by evening out peaks in the influent concentration and the system was piped to allow recirculation between the tank and the air stripper. This recirculation of the treated groundwater allowed multiple passes of the treated groundwater and operation of the air stripper at 15 to 20 gpm with a discharge of 4 to 8 gpm. The water was pumped from the storage tank to the progressive system for primary treatment and then to an imbiber bead filter for secondary treatment. The treated water was discharged to the sanitary sewer system after temporary storage on site.

Hook-up of the air stripper to the tanker was begun the week of June 15, 1992. The first use of the air stripper was begun on June 28, 1992.

6.3.1 Progressive Air Stripper

The innovative progressive system in many respects supersedes the conventional packed column air stripper design. The packed column air stripper is a single air lift, while the progressive air stripper is a series of air stripping lifts. At the bottom of each air stripping lift, air is entrained into the water stream. The air bubbles up the vertical riser tube with the water stream and volatilizes the contaminant at a rate proportional to the Henry's Constant of the volatile contaminant and the temperature of the air and water. At the top of the air lift, the water flows across into the next air lift, forming an air-water interface from which the contaminant-laden air rises into the air collection header.

A progressive system has been operated with success at a National Priority Listed (NPL) site in Pompey, New York, by the USEPA Emergency Response Division, Site Mitigation Section, Edison, New Jersey. After 9 months of operation, the groundwater remediation was deemed complete and the system was removed from the site. The air stripper reduced the contaminants in the water from concentrations of 700 ppb to non-detectable in three months of operation.

6.3.2 Air Stripping Theory

Air stripping efficiency depends on the transfer rate of the contaminant from water to air. A measure of the resistance to mass transfer from water to air is represented by the Henry's Law Constant, (Mackay, et al., 1979). The larger the Henry's Law Constant, the greater the equilibrium concentration of the contaminant in air. Thus, contaminants with large Henry's Law Constants are more easily removed by air stripping (Kavanaugh and Trussell, 1980).

The Henry's Law Constant, vapor pressure and water solubility for each of the organic contaminants identified in the Consent Degree are presented Figure 6-6. Mackay and Wolkoff (1973) and Mackay and Leinonen (1975) suggested that these parameters be combined to give an effective Henry's Law Constant for organic materials in water.

In general, the combination of a high Henry's Law Constant, high vapor pressure and low solubility indicates a potential for successful air stripping. McCarty, et al. (1979) noted that those compounds with a Henry's Constant value greater than 10^{-3} atm-m3/mole, such as tetrachloroethylene, are good candidates for removal by air stripping.

Based on the Henry's Law Constant, vapor pressure, solubility of the compounds of concern at the site, the amenability of each compound to removal by air stripping, ranges from excellent to very good and air stripping is therefore feasible for these compounds.

Air stripping systems that are similar to the progressive system have been demonstrated to achieve greater than 99 percent removal efficiency with tetrachloroethylene.

The progressive system installed at General Switch consists of a series of ten air lifts (Figure 6-5) that in series air strip the volatile contaminants from the well water. The contaminated water discharged to the system from the long term pump test of well W-30 was approximately 2 gpm and, based on past sampling, was expected to contain concentrations of tetrachloroethylene between 95 ppm and 260 ppm.

Air stripping, at each air lift, produces approximately 65 percent removal efficiency. Total treatment efficiency increases with the addition of multiple air lifts. Summed removal percentages are shown on Table 6-6.

To enhance removal of the volatile organic compounds, treated water is recirculated through the air lifts. The average flow rate achieved during water treatment was approximately 4 gpm.

Table 6-7 and 6-8 present some relevant factors effecting air stripping, for various organic compounds.

6.3.3 Transmission Pipes

The water recovered from well W-30 was conveyed to the General Switch parking lot where the air stripper was operated through underground piping. The lines are constructed of 2-inch-diameter Schedule 40 PVC and were installed during the reconditioning of well W-30. Discharge piping from the treatment system was constructed from the treatment trailer to the discharge point into the Wallkill sewer.

6.3.4 Air Discharge Treatment

The air effluent, which is contaminated with volatile organic compounds from the water treatment system, was passed through vapor phase activated carbon for treatment.

The quality of the air effluent from the air stripping of the water drawn from well W-30 was determined through analysis. This information will be presented to the Air Branch of the NYSDEC for the equivalent of an air permit review for the operation of the air stripper. Authorization to operate the system will be obtained from USEPA and NYSDEC prior to initiating the final groundwater cleanup.

6.3.5 O&M Requirements

Air stripping requires minimal operator attention, maintenance of the pumps and blowers, and electricity. The stripper itself contains no moving parts. Attention to mineral deposition and biological matting of the column packing is not required. However, occasional cleaning of the stripper trays is necessary, but this task can be done relatively easily with a minor amount of labor.

6.3.6 Efficiency of the Operation of the Air Stripper

Samples of the water were collected at several locations to document water quality. Cumulative sample results are contained in Table 6-9. Water samples of the influent to the air stripper, the effluent discharge from the air stripper, the influent to the

Wallkill treatment plant (located approximately 3 miles from the General Switch site), and effluent from the Wallkill treatment plant into the Wallkill River (located adjacent to the plant). Water samples were analyzed for volatile organic compounds using the Photovac, with confirmatory duplicates analyzed by the laboratory.

Information regarding the effectiveness of water treatment by the air stripper was evaluated by comparing analytical results of the influent and effluent samples. The removal efficiency is calculated by dividing the difference in influent and effluent concentrations by the influent concentration, and multiplying by 100%. This information is presented in a graph of concentration plotted against the time since the beginning of pumping to ascertain any trends in groundwater concentration and treatment efficiency (Figure 6-8, Table 6-7). The removal efficiency was shown to be greater than 99%.

6.3.7 Photovac Samples of Air Stripper Influent and Effluent

Water samples of the influent to the air stripper and the effluent from the air stripper were tested with the Photovac. Photovac analysis of the influent water samples indicated that tetrachloroethylene was detected in the influent water at concentrations of approximately 20 ppm. Analysis of the effluent samples indicated that no volatiles were detected after treatment.

6.3.8 Laboratory Samples of Air Stripper Influent and Effluent

On June 6, 1992, a sample of the groundwater pumped into the air stripper was obtained from the tanker staged on site for temporary storage of contaminated water. The grab sample of the water stored in the tanker (sample number 1310203) was analyzed by the laboratory. Laboratory results indicate that approximately 1,100 ug/l (ppb) tetrachloroethylene was being pumped into the air stripper. An effluent sample (sample 131204) was analyzed and found to contain approximately 2 ug/l (ppb) tetrachloroethylene. These samples were transported to NYTEST Laboratory for analysis. Based upon the analytical results, permission was received to discharge approximately 7,000 gallons of treated water to the Wallkill sewerage plant.

It is noted that the influent sample (1310203) contained acetone at 149 ug/l (ppb), which may be attributable to the decontamination procedure being used on site, and butanone, at 66 ug/l (ppb), which may be derived from decaying vegetable matter. Acetone is readily soluble in water and therefore is extremely difficult to air strip. As expected, acetone was detected at a concentration of 46 ug/l (ppb) after air stripping.

On September 18, 1992, purged well water was pumped into the holding tank with tetrachloroethylene ranging in concentration from 12 ug/l (ppb) from well MW-14 to 41,000 ug/l (ppb) from well MW-5. This groundwater was treated by the air stripper to non-detectable concentrations for tetrachloroethylene and was subsequently discharged to the sewer system.

It appears that there are one or more sources of tetrachloroethylene entering the sewer system. Analysis of sample 1408613, collected from the influent stream to the sewage plant, indicates that tetrachloroethylene at a concentration of 1.9 ug/l (ppb), chloroform at a concentration of 11 ug/l (ppb), and other volatile organics were detected in the sewage plant pretreatment stream, while analysis of the air stripper discharge indicated that no volatiles were detected.

The concentration of volatile organics in the treatment plant effluent (discharge to the Wallkill River) was lower than that of the influent stream. The sewage plant effluent sample (number 1408614) contained 1.0 ug/l (ppb) bromochloromethane and 3.2 ug/l (ppb) chloroform, but none of the samples from the Wallkill River showed any tetrachloroethylene.

On September 30, 1992, duplicate samples of the groundwater pumped into the air stripper were collected. Tetrachloroethylene was detected in duplicate sample (number 1419598) between 5,200 ug/l and 2,300 ug/l. The air stripper reduced the volatile organic groundwater contaminant concentration to non detected for tetrachloroethylene. The method detection limits were 5 ppb for tetrachloroethylene, trichloroethylene and dichloroethylene and 2 ppb for vinyl chloride. Thus, the groundwater was treated to the cleanup standards set forth in the Consent Decree. The water was subsequently discharged into the Wallkill sewer system.

This information will be used in order to obtain authorization from NYSDEC and the Town of Wallkill to discharge the effluent (treated groundwater) to the Wallkill sewer during the full-scale groundwater cleanup.

Based on the sample collected on September 30, 1992, from the influent to the sewage system, it is apparent that there is a source other than General Switch for tetrachloroethylene. Tetrachloroethylene was detected at a concentration of 22 ug/l in sample 1419512 along with seven other volatiles at lesser concentrations. The contamination was reduced in the treatment plant such that only 1.6 ug/l of tetrachloroethylene was detected in sample 1419514 of the effluent from the treatment plant into the Wallkill River.

6.3.9 Air Stripper Residence Time

A Rhodamine dye was injected into the air stripper treatment system to determine the residence time for groundwater in the treatment system. The residence time data is useful so that samples of water at a specific concentration entering the system can be compared to the same water leaving the system after treatment. The residence time in the air stripper was measured to be approximately 1 minute 20 seconds. On the day of the dye test it took 2 hours for the dye to arrive at the Cottage Street sewer manhole. Subsequent dilution prevented further downstream tracing as the red hue was not detectable.

6.3.10 Interferences

High iron content groundwater interferes with the operation of conventional packed column air stripping of volatile organics. The iron in the water is oxidized in the presence of air and forms a iron precipitate which is deposited on the packing material. This problem was avoided with the airlift system in that there is no packing media used in the stripper. No problems were encountered during the operation of the air stripper that involved fouling of the injection jets or build up of iron. The transparent tubing on the air lifts became more opaque; however, this did not obscure a view of the turbulent mixing in the air lifts.

Reliability of air stripping can be a problem where cold weather operation is required. Since the rate of air stripping is a function of temperature, cold weather decreases the rate of volatilization. Heating the blower air or influent water may be required for winter operation to maintain optimum removal efficiency. The air stripper was operated on December 22, 1992, when the ambient temperatures never rose above freezing and no significant problems were encountered; however, long-term winter operations can be problematic in that freezing water can occur and disrupt operations.

6.3.11 Summary

In summary, during the study period from May 1992 to April 2, 1993, the influent concentrations of tetrachloroethylene pumped to the air stripper ranged from 22 ppb to 9,700 ppb. The effluent concentrations from the stripper ranged from non-detected to 7.2 ppb. The influent concentrations from all Wallkill sources flowing into the Wallkill sewage treatment plant ranged from 1 ppb to 22 ppb, and the Wallkill River samples showed no tetrachloroethylene throughout the study period.

6.4 REFERENCES

A Practical Approach to the Design, Operation, and Monitoring of In-Situ Soil Venting Systems, P.C. Johnson, M.W. Kemblowski, J.D. Colthart, D.L. Byers, and C.C. Stanley, 1989.

Soil Vapor Extraction Technology EPA/540/2-91/003 February, 1991.

SECTION 7

CONTENTS

CONTENTS
(Continued)

7.0 CONTAMINANT TRANSPORT AND FATE

7.1 INTRODUCTION

Previous sections of this Report discuss the extent of volatile organics contamination at the site. This section presents the routes of migration of the volatile organics, primarily tetrachloroethylene (PCE), and addresses the persistence of contaminants in the bedrock aquifer. Actual and potential routes of migration of contaminants in the vadose zone, groundwater (overburden and bedrock) and surface water are identified along with contaminant persistence.

In order to understand the distribution of solvent contaminants in the soil, air and groundwater at the site, the physical characteristics on these solvents and their interaction with the site geology and hydrology must be evaluated. The potential leachate discharges and other forms of pollutant dispersion pathways are documented as follows.

7.2 POTENTIAL PATHWAYS OF CONTAMINANT DISPERSION

The contaminants consist of solvents which were spilled at two locations, identified as hot spots TP-A and TP-D. Solvent contamination was also detected at TP-6, in the shallow aquifer beneath the wetlands and in the bedrock aquifer along Highland Avenue (Figure 7-1).

7.2.1 Areas of Potential Soil Contamination

Area TP-A

At TP-A, the maximum concentration of solvents in the soil reached 5,500 parts per million (ppm) tetrachloroethylene (in SB-6), and more than 50 ppm was detected at the top of bedrock. Free product, possibly originating from TP-A, was detected in the bedrock at well W-30 (the Parella well) only. The concentrations of tetrachloroethylene detected at TP-A represent the residual contamination after the solvent infiltrated to the bedrock.

Area TP-D

The loading dock is identified as area TP-D. The sample collected from soil boring SB-12 at 6-8 feet depth had a tetrachloroethylene concentration of 50 ppm. The soil sample immediately above the bedrock at 22-24 feet depth contained PCE at 370 ppm. The borings surrounding SB-12 contained soils with less than 50 ppm tetrachloroethylene. Only limited spillage of solvents is assumed to have occurred at the loading dock.

Area TP-6

The contamination of groundwater and soil around TP-6 probably occurred as a result of seepage through the fill of the parking lot on top of the glacial till of tetrachloroethylene from area TP-D. There is no evidence that any spillage of solvent occurred on the ground surface at TP-6. As indicated by the soil sampling conducted in area TP-6, this is a secondary source from lateral seepage.

7.2.2 Site Hydrology - The Relationship of Surface and Groundwater Systems

Details of the geohydrologic conditions at the site were determined to assess the past and potential pathways for migration of the solvents.

The wetlands at the site was observed to receive significant amounts of runoff collected as ponds in the wetlands. The 16-40° NW, sloping bedding planes of the shale bedrock observed in the outcrop adjacent to Lubricants Inc., approximately 600 feet east of the General Switch site, are fractured by near-vertical fissures. The bedrock is covered with a thin layer of glacial till. This glacial till, as indicated by the physical testing, slug testing and permeability field testing, has a low impermeability (Section 3). Any precipitation or solvent spilled on the hillside has to permeate the glacial till before entering the bedrock. The open vertical fissures would allow the water to infiltrate into the bedrock and recharge the underlying shale. Recharge is particularly noted in the wetlands as the surface ponding which disappears from the surface.

7.2.3 Leachate Run-off and Surface Water Infiltration

It is apparent that contaminants are dispersed from the two original hot spots TP-A and TP-D in two major ways: by bulk movement of pure solvent through the soil and as dissolved solvent leached from the hot spots by precipitation and groundwater that moves through the soil. There are no surface streams present on the site to carry away contaminated soil and dissolved contaminants by overland flow. Thus, leachate is generated by precipitation moving through the soils of the hot spots, infiltrating the bedrock and moving with the groundwater flow regime.

7.2.4 Free Product - Dense Non-Aqueous Phase Liquid (DNAPL)

In 1992, dense non-aqueous phase liquid (DNAPL) was observed in well W-30. This DNAPL is currently being recovered from well W-30.

A pumping test of well W-30 was conducted between October 17, 1983, and December 26, 1983. The results indicate that, during the period between the end of October and the middle of November, the concentration of tetrachloroethylene in the water pumped from well W-30 was 260 ppm, which may be in excess of the solubility of this chemical. This was the first indication that there was potential for free product in well W-30. DNAPL present in the aquifer beneath the site will act as a continuing source of dissolved phase groundwater contamination. DNAPL in the subsurface is a long-term sources of groundwater contamination, and may persist for decades before dissolving completely in adjacent groundwater.

The presence of DNAPL is significant because transport of DNAPL can be very different than transport of dissolved material. This section addresses the fate and transport of separate phase DNAPL dissolved phase and contamination. At present, there are two different sources of groundwater contamination at the site. The contaminated soils located next to the General Switch facility, and the DNAPL in the surface and fractures of the bedrock act as separate sources of groundwater contamination.

7.2.5 Airborne Dispersion

Air dispersion is not a significant pathway at the present time.

Air monitoring conducted during site activities indicates that ambient levels at the hot spots and at the air stripper generally did not exceed background levels. The only time respiratory protection (Level C) was required during the site investigation was during the drilling of the soil borings at hot spot TP-A.

7.2.6 Groundwater Contamination Dispersed in the Glacial Till

Groundwater tetrachloroethylene contamination at MW-4 (20,000 ppb) and at MW-9 (2,700 ppb) is downgradient from MW-5 and area TP-D. The direction of groundwater flow in the glacial till is generally to the south-southeast. Thus, the most significant groundwater contamination in the wetlands appears to have migrated from TP-D and has reached MW-9, located approximately 500 feet into the wetlands.

The well search conducted of the immediate area (see Section 3 and Appendix 3) indicated that there are no receptors (drinking water wells) downgradient from the wetlands. The level of groundwater contamination in the wetlands far exceeds the maximum contaminant level (MCL) for tetrachloroethylene at MW-4 and MW-9 and prompts inclusion of the wetlands in the area of groundwater capture and cleanup along with the documented groundwater plume in the bedrock.

7.3 PHYSICAL PROPERTIES OF THE DNAPL

It is important to understand the characteristics of the chlorinated solvent DNAPL which determine its movement and persistence. In order to determine the extent of DNAPL contamination and prepare to clean up the aquifer.

DNAPL can be broadly classified on the basis of physical properties such as solubility, density, and viscosity.

The physical properties of tetrachloroethylene are summarized as follows (USEPA, 1986):

- Solubility 1.50 E+02 mg/l
- Density 1.625 g/cc
- Viscosity 0.89 cp

The physical properties indicate that tetrachloroethylene is not readily soluble, it sinks in water and it has the potential to be more mobile in the subsurface than water due to its low viscosity. Details of the physical properties of tetrachloroethylene DNAPL are presented in Appendix 7-A.

7.4 PHYSICAL PROPERTIES OF THE SOIL AND ROCK

Movement of the solvent DNAPL is remarkably sensitive to the capillary properties of the subsurface, and the distribution of those properties in relation to dense liquid flow controls the distribution of the DNAPL. Thus, knowledge of geologic conditions is relatively more important than knowledge of hydrogeologic conditions to adequately characterize the movement and fate of DNAPL at this site.

7.4.1 Capillary Pressure

The capillary pressure of the soil at the hot spot is important in the solvent DNAPL transport because it largely determines the magnitude of the residual saturation that was left behind after a spill incident. The greater the capillary pressure, the greater the potential for residual saturation. In general, the capillary pressure increases in the following order; gravel, sand, silt, clay. Glacial till has a high capillary pressure due to the abundance of silts and clays. Correspondingly, the residual saturation increases in the same order.

7.4.2 Pore Size Distribution/Initial Moisture Content

Residual saturation resulting from a DNAPL spill in the unsaturated zone is highly dependent on the antecedent moisture content in the porous media. When the moisture content is low, the strong capillary forces in the smaller pores will retain the soil pore water, and DNAPL residual saturation will mainly occur in the larger pores. Therefore, greater residual saturation can be expected in dryer soils. Correspondingly, DNAPL will migrate further in a wetter soil, and displacement of DNAPL from small pores is expected to be more difficult than from large pores.

7.4.3 Residual Saturation

In the unsaturated zone during low moisture conditions, the DNAPL residual saturation will wet the grains in a pendular state (a ring of liquid wrapped around the contact point of a pair of adjacent grains). During high moisture conditions, the wetting fluid, which is typically water, will preferentially occupy the pendular area of adjacent grains and the hydrocarbon will occupy other available pore space, possibly as isolated droplets. In the saturated zone, the DNAPL residual saturation will be present as isolated drops in the open pores (47). Laboratory experiments indicate that vadose zone residual saturation is roughly one third less than the residual saturation in the saturated zone (66). The increase in residual saturation in the saturated zone is due to the following: (1) the fluid density ratio (DNAPL:air versus DNAPL:water above and below the water table, respectively) favors greater drainage in the vadose zone; (2) as the non-wetting fluid in most saturated media, DNAPL is trapped in the larger pores; and (3) as the wetting fluid in the vadose zone, NAPL tends to spread into adjacent pores and leave a lower residual content behind, a process that is inhibited in the saturated zone (36). Thus, the capacity for retention of DNAPLs in the unsaturated zone is less than the saturated zone.

7.4.4 Stratigraphic Gradient

The DNAPL migrating vertically through the glacial till encountered the shale bedrock zone or stratigraphic unit of lower vertical permeability. A reduction in the vertical permeability of the porous media would induce lateral flow of the DNAPL. The slope of the lower permeable stratigraphic unit will largely determine the direction in which the DNAPL will flow. As depicted in Figure 7-2 and 7-2A, the lateral direction of DNAPL flow may be in a different direction than groundwater flow.

7.4.5 Groundwater Flow Velocity

The groundwater flow velocity is a force which tends to mobilize the contaminant (39). As the groundwater velocity increases, the dynamic pressure and viscous forces increase. Mobilization of DNAPL occurs when the viscous forces of the groundwater acting on the DNAPL, exceeds the porous media capillary forces retaining the DNAPL.

7.4.6 Relative Permeability

Relative permeability is defined as the ratio of the permeability of a fluid at a given saturation to its permeability at 100% saturation. Thus, relative permeability values range between 0 and 1 (71).

Figure 7-3 illustrates a relative permeability graph for a two-fluid phase system showing the relationship between the observed permeability of each fluid for various saturations to that of the observed permeability if the sample were 100% saturated with that fluid (73). The three regions of this graph are explained as follows (71):

Region I has a high saturation of DNAPL and is considered a continuous phase while the water is a discontinuous phase; therefore, water permeability is low. Assuming the DNAPL is the non-wetting fluid, water would fill the smaller capillaries and flow through small irregular pores.

In Region II, both water and DNAPL are continuous phases, although not necessarily in the same pores. Both water and DNAPL flow simultaneously. However, as saturation of either phase increases, the relative permeability of the other phase correspondingly decreases.

Region III exhibits a high saturation of water while the DNAPL phase is mainly discontinuous. Water flow dominates this region and there is little or no flow of DNAPL.

Both fluids flow through only a part of the pore space and thus, only a part of the cross section under consideration is available for flow of each fluid. Therefore, the discharge of each fluid must be lower corresponding to its proportion of the cross sectional area (46).

Small increases in DNAPL saturation result in a significant reduction in the relative permeability of water. However, a small increase in water saturation does not result in a significant reduction in DNAPL relative permeability. This figure identifies two points, SO1 and SO2, where the saturation of the DNAPL and the water are greater than 0 before there is a relative permeability for this fluid. The two fluids hinder the movement of the other to different degrees and both must reach a minimum saturation before they achieve any mobility at all (47). These minimum saturations for the water and DNAPL are identified as irreducible and residual saturation, respectively.

7.4.7 Effect of Solvents on Hydraulic Conductivity of the Glacial Till

For the solvent to have reached the bedrock under the hot spots, the solvent would have had to pass through relatively impermeable glacial till. According to the results of the slug testing of the glacial till overburden, the glacial till has hydraulic conductivity ranging from 0.1069 E-04 to 19.81 E-04 ft/min (see section 4).

Laboratory results of physical testing of soils treated with organic solvents have shown a wide variation in hydraulic conductivity. However, the most important findings indicate that while organic solvents at low concentrations do not significantly affect hydraulic conductivity, pure product can cause major fluctuations in the hydraulic conductivity of soils.

The effects of an organic solvent on hydraulic conductivity can be estimated by reviewing the dielectric constant of the compound of concern. Compounds with low dielectric constants, such as tetrachloroethylene, decrease the double layer thickness of the clay particles, thus creating flocculation. Flocculated clays have increased hydraulic conductivity due to increased micro and macro pore structures which allows fluids to pass through more readily. The glacial till that forms the overburden across the site contains significant amounts of clay. Thus, free phase solvents with low dielectric constants have the ability to shrink such soils, creating fissures in the clay to allow downward movement to the bedrock. The low viscosity of tetrachloroethylene along with its ability to shrink clays accounts in part for its penetration of the overburden and discharge into the bedrock.

7.5 SOLVENT DISTRIBUTION IN SOIL - A FOUR-PHASE SYSTEM

The General Switch site fits the general scenario of a release of DNAPL into the soil which subsequently migrates vertically under both the forces of gravity and soil capillarity to reach the fractured bedrock and migrates in regional fractures to well W-30.

There are four possible phases in the unsaturated zone: gaseous, solid, water, and immiscible hydrocarbon (DNAPL). Contaminants associated with the release of DNAPL can, therefore, occur in four phases described as follows:

1. Air phase - contaminants may be present as vapors.

2. Solid phase - contaminants may adsorb or partition onto the soil or aquifer material.

3. Water phase - contaminants may dissolve into the water according to their solubility.

4. Immiscible phase - contaminants may be present as dense non-aqueous phase liquids.

The lateral migration of the DNAPL in the overburden was determined by the soil capillarity. In leaving behind the residual soil contamination in the overburden, a point is reached at which the DNAPL no longer holds together as a continuous phase, but rather remains as isolated residual globules. The fraction of the hydrocarbon referred to as residual saturation is retained by capillary forces in the porous media. The main mobilization mechanism of the solvent in the residual saturation is removal of soluble phase components into the groundwater.

7.6 MOVEMENT OF DNAPL IN THE SUBSURFACE UNSATURATED (VADOSE) SOILS

Considering the physical characteristics of the DNAPL (see Appendix 7A) and the extent of contamination reported in Section 5, the following conclusions can be made regarding the fate and transport of the solvent DNAPL at General Switch.

When the tetrachloroethylene infiltrated the soil at TP-A and TP-D as a non-aqueous liquid, the seepage was controlled predominantly by gravity, viscous forces, and capillary forces, which were in turn controlled by the interactions of water, soil/aquifer material, and the non-aqueous liquid. Properties of the soil which influenced the mobility of the non-aqueous liquid included soil heterogeneity, intrinsic permeability, mineralogy, pore size, pore geometry and macropores. The DNAPL migration was also influenced greatly by structural and stratigraphic features.

From research on movement of DNAPL, gravity forces generally dominate DNAPL movement until the immiscible liquid reaches a permeability contrast. Capillary forces may inhibit penetration of the DNAPL into the less permeable zone. Often DNAPL will move along bedding planes in the direction of the geologic dip in the downslope direction of the bedrock surface, even in a direction opposite to groundwater flow. The actual direction of DNAPL movement depends on the dip of the underlying strata, the capillary and viscous forces, and the density contrast. DNAPL will flow along the surface of a low permeability layer until an obstruction is encountered. DNAPL will also migrate in fractured material in very complex patterns. The bedrock surface geometry indicates that DNAPL may flow along the top of the bedrock in the direction toward well W-30.

At TP-A, the highest concentrations of solvent are found at OB-9 and SB-6, in a topographic low adjacent to the building where the DNAPL evidently pooled. In order for the DNAPL to have reached well W-30 as free product, the solvent had to have migrated downward through the vadose zone initially as a free product liquid.

As indicated by the results of the soil borings, vertical migration was accompanied by some limited lateral spreading due to capillary forces and soil heterogeneities. Residual liquid remained trapped by surface tension in pore space as the DNAPL drained through the soil. As noted during the VES test, DNAPL also dissolved into residual soil water and vaporized into soil gas.

7.7 SOLVENT DISTRIBUTION IN THE GROUNDWATER

Contaminated groundwater was encountered in the saturated overburden and in the bedrock at the site.

7.7.1 DNAPL in the Saturated Zone

The General Switch site fits the general scenario where the volume of DNAPL was sufficient to overcome the fraction depleted by the residual saturation in the vadose zone, as illustrated in Figure 7-4. Consequently, the DNAPL reached the water table as evidenced by the product detected in well W-30 and contaminated the groundwater directly. The DNAPL overcame the resistance posed by the capillary fringe and migrated into the saturated zone, in other words the DNAPL volume was not exhausted by the residual saturation of the soil. DNAPL continued the vertical migration through the saturated zone until it intercepted a low-permeable formation where it began to migrate laterally.

As evidenced by the rock cores and the results of the packer testing, the Austin Glen Shale contains a myriad of fractures of various lengths, widths, and dips. DNAPL introduced into fractured formations (Figure 7-5 and 7-5A) follows complex pathways due to the heterogeneous distribution of the cracks, conduits, and fractures.

Relatively small volumes of DNAPL may move quickly through fractured rock because the amount of DNAPL immobilized by dead-end fractures and the immobile fragments and globules in the small fractures is relatively minor (32). Currently, the capability to collect the detailed information for a complete description of DNAPL distributed in a contaminated fractured rock system is regarded as neither technically possible nor economically feasible (61).

7.7.2 DNAPL Phase Distribution in the Groundwater - A Three-Phase System

Because of the lack of the gaseous phase, the saturated zone containing DNAPL is considered a three-phase system consisting of the solid, water, and immiscible product phases. In a non-fractured bedrock aquifer, the hydraulic conductivity in the vertical direction is typically less than in the horizontal direction. It is not uncommon to find vertical conductivity that is one-fifth or one-tenth the horizontal value (4). Thus, DNAPL spilled into the subsurface would have a significant potential to migrate laterally. For fractured bedrock aquifers, the vertical and horizontal hydraulic conductivities will vary greatly, depending on the nature and extent of fracturing.

7.7.3 DNAPL Movement in Groundwater

Sufficient DNAPL would be required to overcome the capillary (entry) pressure at the saturated-unsaturated zone interface. Once DNAPL penetrated the saturated zone, it continued to migrate downward driven by gravity. The water table is encountered at a depth of 2 feet in TP-A and at 16 feet in TP-D. Preferential flow would have occurred where DNAPL encountered relatively permeable layers and fractures.

The strike of bedding for the Austin Glen Series is northeast-southwest, and the regional dip is 16-40° NW observed in local outcrops on Industrial Place. Beds of the shale that outcrop in the base of TPA at 12 feet below ground surface would also intersect W-30 near the ground surface.

The ultimate location of DNAPL in the subsurface spread to well W-30, 200 feet from the DNAPL entry location. It is probable that, in addition to accumulating in DNAPL pools, residual DNAPL was trapped in pore spaces within the saturated zone. The dissolution of DNAPL constituents into passing groundwater has resulted in the contamination of large volumes of groundwater for over 8 years, and the groundwater contamination has been kept at high concentrations by contact with the pure product.

The magnitude of capillary pressure resisting passage of DNAPL through a water-saturated, porous medium is inversely proportional to the size of pore openings. The DNAPL, therefore, probably migrated preferentially through relatively permeable pathways in the saturated glacial till such as fractures, root holes, and sandy layers, and was probably influenced by small-scale textural changes. While the glacial till at the General Switch site is relatively impermeable, this aquitard has not prevented the downward leakage of the DNAPL. Thus, the normal concept of a confining layer commonly used in hydrogeology is inappropriate at such DNAPL sites.

Laboratory experiments have demonstrated that aqueous phase chemical concentrations in contact with non-aqueous phase liquids approach effective solubilities (saturation) rapidly. For low and moderate groundwater flow rates, it would be logical to expect saturated dissolved concentrations in groundwater leaving the DNAPL zone.

Relatively low aqueous concentrations in wells within the plume probably result from: the variable distribution of DNAPL as residuals, lenses, and pools; aquifer dispersion; non-uniform groundwater flow; dilution in monitoring wells; and failure to account for effective rather than pure-phase solubilities. Importantly, field observations of low aqueous concentrations do not support the absence of a DNAPL phase, as demonstrated at known DNAPL sites.

Unless a monitoring well is installed very close to the DNAPL zone and the well intake is short, saturated or near-saturated levels of dissolved constituents will not be observed. Depending on the distribution of DNAPL, low groundwater concentrations can be found even in the immediate proximity of the DNAPL. The concentration of tetrachloroethylene in groundwater at MW-202 has been detected as high as 25,000 ug/kg (ppb), which indicates that DNAPL may be found near MW-202 between TP-A and well W-30.

7.7.4 Groundwater Flow Systems in the Shale Aquifer

The pure product dissolved in the groundwater and leachate generated from the hot spots have formed a dissolved solvent plume in the glacial till and bedrock. These dissolved components follow the normal regional groundwater flow patterns, but are influenced by pumping of residential wells. In order to understand the movement of contaminants in the groundwater, flow regimes under natural flow and under pumping conditions must be fully characterized.

The wells located along Highland Avenue draw groundwater from a semi-confined bedrock aquifer. Aquifers are bodies of soil or rock that contain groundwater and are commonly divided into two types, unconfined and confined, on the basis of stratigraphic setting and hydraulic pressure head relationships. Unconfined aquifers have an upper water surface (water table) that rises and falls freely in response to the volume of water in storage in the aquifer.

The bedrock under the General Switch property and along Highland Avenue is covered with a thin layer of glacial till that forms a cap or confining unit on the top of the bedrock and tends to exclude the groundwater rising under pressure into the base of the glacial till. In an unconfined aquifer, the water table is a free surface open to, and in pressure equilibrium with, the atmosphere. In a confined aquifer, the groundwater is under pressure such that it would rise in a well to a level above the top of the aquifer.

The groundwater in the shale aquifer occurs in a semi-confined aquifer beneath a lower permeability confining unit, the glacial till. Pressure in the aquifer is greater than atmospheric, so that water rises above the base of the confining unit in a well penetrating the aquifer, but some groundwater is contributed from the glacial till and wetlands as vertical leakage. This was seen in the soil brings drilled by Fred C. Hart in 1984 and in the monitoring wells drilled in 1992 to the top of the bedrock. During drilling of MW-15, groundwater, encountered at the top of bedrock, rose inside the well to a level above the top of the ground surface.

The depth to an aquifer and the nature of the unsaturated zone above an aquifer can be significant in controlling how rapidly contaminants are able to migrate downward to the aquifer. Where bedrock is exposed or the surface soil is extremely thin, such as with the Lubricants Inc. facility, the contaminants are free to infiltrate directly into fissures in the bedrock.

7.7.5 Confined Fractured Bedrock Aquifer

Fractured bedrock aquifers share many characteristics with karst (limestone) aquifers. Under conduit flow conditions, contaminants can be transported quite rapidly in the system from their point of introduction to the point of impact, with only minimal dilution or dispersion. Thus, small volumes of DNAPL could migrate through bedrock to well W-30 without significant diminution. Similarly, conduit flow conditions can often undergo rapid flushing of contaminants from the system.

As a result of different conducting fractures within a fractured bedrock system, contaminants in one set of fractures may not interconnect with adjacent fractures. Thus, the pattern of groundwater quality can differ considerably and one well may be contaminated while a nearby well escapes the impact. In this way, the Gilbert well (W-11) has remained free of contamination, yet the Stout (W-32) residential well across Highland Avenue has contained tetrachloroethylene at concentrations between 1,100 ppb tetrachloroethylene in the first groundwater sample round and 160 ppb in the second round.

The fractured shale bedrock aquifer at the General Switch site is typical of such aquifers in that it has relatively little storage capacity in the primary porosity of the bedrock compared to that of the secondary porosity (i.e., fractures). If fractured bedrock aquifers are capable of significant water supply, this is usually the result of interconnections with alluvial aquifers, saturated saprolites, or surface water infiltration. This is not the case at the General Switch site, except that a reservoir of groundwater was encountered in the Contel (W-33) and Barry wells (W-17) at the fractured and weathered top of bedrock. Individual wells, such as MW-207 and well W-33, tap major fractures that are prolific and yield between 6 to 15 gpm. The majority of wells at the site yield less than 2 gallons per minute.

7.7.6 Natural Flow System

A general description of groundwater flow systems follows, along with a description of the influence of pumping wells on such a system. The description is presented to explain the groundwater flow system along Highland Avenue.

The direction of groundwater flow in the bedrock as plotted in Figures 4-7 and 4-13 is approximately due southeast. At this site, the regional groundwater flow from the ridge to the Guild Molders and Wallace Oil facilities located in the valley bottom along Industrial Avenue Extension. The motion of groundwater through the aquifer is controlled by differences in piezometric head. Groundwater moves from areas of higher energy to areas of lower energy in order to reach or maintain a state of equilibrium. The regional groundwater flow at the base of the glacial till thus tends to flow from the high elevations along Highland Avenue to Industrial Place, as indicated in Figures 4-7 and 4-13. The fundamental equation that expresses the underlying concept governing groundwater flow is that "total head" (h) of a unit volume of fluid at a location is equivalent to the sum of the "pressure head" and the "elevation head" (i.e., the sum of the amount of pressure the groundwater is under, expressed in feet of water column and the height above sea level). If the total heads at two points in an aquifer differ, groundwater will flow from the high-head point to the low-head point.

7.7.7 Transport in Dissolved Phase

While the direction of groundwater flow in the glacial till for October 14, 1992, presented in Map 4-A, is due southeast, the pattern of groundwater contamination in the bedrock is spread out from east to west. This indicates that the direction of travel of the contaminants was controlled by other factors than the present regional direction of groundwater flow.

The groundwater contours plotted from the bedrock aquifer taken on or about October 27, 1992, indicate a more westerly direction of groundwater flow. At that time 11 wells were being used to supply groundwater for the residences along Highland Avenue in the vicinity of the plume, including W-18 (Ruppert), W-17 (Barry), Liska, W-13 (Ogden, formerly Wood), W-12 (Seeley), W-11 (Gilbert), W-32 (Stout), W-30 (Parella), Fiore, Lobb and W-8 (Osbourne). The amount of groundwater available to these wells was limited as on occasion these wells would run dry. These wells were interconnected according to pump tests conducted in the fall of 1992 and competed with each other for available groundwater.

The overuse of wells along Highland Avenue was noted by local drillers who over the years drilled deeper wells, to 200 feet, along Highland Avenue because the early wells drilled to 100 feet were made less prolific as the water table dropped an estimated 20 feet. In Graph 7.1, the date of well completion is compared to the depth of the well, indicating that wells drilled in later years were drilled deeper to tap water in an overpumped aquifer, as presented in Wallkill Well Data, Appendix 3.

This pumping of groundwater had a significant influence on the migration of tetrachloroethylene groundwater; the direction of solvent migration was altered from the southern direction to the west.

The existence of fractured bedrock at the site complicates the movement of groundwater and dissolved contaminants. An understanding of the nature and orientation of these fractures is essential to define the movement of groundwater contamination and to design an effective pump-and-treat recovery system in the bedrock.

The geophysical survey detailed in Section 3 indicates the major fractures trend east-west. Pumping at the southwest ends of these fractures along Highland Avenue influences the groundwater to move in a more south westerly direction.

7.7.8 Pumping of Groundwater and Flow to a Well

Under natural conditions, an aquifer is in a state of dynamic equilibrium. That is, if the elevation of the water table is not changing and the total recharge to the aquifer is equal to the total discharge, with no change over time in the volume of water stored in the aquifer, the aquifer is considered to be at equilibrium (Fetter, 1980).

During normal use of a well, groundwater pumping to obtain drinking water from the aquifer alters the state of equilibrium in an aquifer. The withdrawal of water by a well causes a lowering (drawdown) of water levels in an area around the well. From a spatial perspective, this is referred to as the area of influence of a well, or its zone of influence. In cross-section, this is commonly referred to as the cone of depression. Within the zone of influence, flow velocities increase toward the well, due to increased hydraulic gradients.

Figure 7-6 illustrates the effects of a pumping well on the groundwater flow system and that the equipotential and flow lines for the "natural" (non-pumping) conditions have been distorted, and are directed toward the well. This distortion causes an area of groundwater recharge to the well. The pumping does not affect the flow lines outside of that area. It should also be noted that the pumping of the well causes some of the groundwater that previously flowed past the well to reverse its path and flow back toward the well. The entire area recharging or contributing water to the well or well field is called the zone of contribution or capture zone.

Any environmental impact on the recharge of groundwater within the zone of contribution has the potential to affect the water quality of the well. The contaminants may travel rapidly toward the well once they enter the portion of a zone of contribution where groundwater velocities are increased due to increased hydraulic gradients. Figure 7-7 is a diagram of the groundwater flow toward a pumping well.

The areal extent of the zone of contribution can increase with time as the well continues to pump. These transient zones are referred to as "time-related capture zones" and, in time, will reach an equilibrium, with no further expansion, that is related to the rate of pumping.

There is a limit to the amount of water each of the wells on Highland Avenue and each of the monitoring wells will produce. For each well, there is a relationship between the amount of water produced and the amount of drawdown the pumping rate produces (specific yield). The wells in the site area yield between 3 and 30 gallons per minute. The variation in well yields is due to differences in well depths, and whether the well penetrated a prolific fissure.

The bedrock monitor wells and residential supply wells are open hole wells below a surface casing and are finished at varying depths in the shale bedrock. The depth of well completion is determined by the availability of groundwater. High on the slope the wells are deep (200 feet plus) in order to tap all the overlying rock formations.

The limit to the rate that water can be pumped from each well before the well is pumped dry is referred to as maximum yield. Thus, there is a limit for expansion of the zone of contribution for each recovery well in that each well can only pump at a certain maximum rate above which the well will be pumped dry.

The two zones described above (zone of contribution and zone of influence) are important because of their significance to an understanding of the contamination of a well. The zone of contribution is of great importance because contaminants introduced within this zone could reach a well. In such situations, contaminants within surface soils or from other parts of the aquifer can be induced to move toward the pumping well.

The contributing area (zone of contribution) and the area of influence (zone of influence) are not identical. When the pre-pumping water table has a gradient, as it does under most natural conditions, the contributing area to a well will be distorted to extend to a greater distance on the upgradient side and to a lesser distance on the downgradient side. The contributing area at this site is also influenced by fissures in the rock along which the groundwater flows (Figure 7-8).

The wells in the study area are sensitive to overpumping, condition which occurs when the rate of water removed from the aquifer is greater that the rate of recharge, resulting in depression of the water table. During overpumping, significant changes in the direction of groundwater velocities occur and the zone of influence of the well is greatly extended.

Generally, the most significant process controlling the movement of dissolved contaminants within the zone of contribution is called "advection," in which contaminants are carried toward a well by the bulk motion of the flowing groundwater. Chemical, biological, and physical processes other than advection may affect the fate of contaminants in the groundwater. Retardation and dispersion are two processes that respectively slow and accelerate the movement of a contaminant toward a pumping well.

The groundwater in the bedrock aquifer at the site flows through a system of interconnected fractures. It is not unusual for a prolific well in a fractured medium to draw down wells at a considerable distance because the available water is restricted to fractures. The restriction of groundwater to fractures means that the available water is drawn to supply the wells from an extended area under the hillside. When the same fracture system is tapped by two wells, they are interconnected.

7.7.9 Transport of Contaminants to a Well

To define the area that has impact upon a well, the zone of contribution is first determined. Factors that influence the flow of water to a well include aquifer and flow characteristics such as hydraulic conductivity, hydraulic gradient, aquifer thickness and the pumping discharge rate.

In Figure 7-9, a pumping well is shown to have created a cone of depression within an unconfined groundwater flow system. The zone of influence of the well is the area overlying the cone of depression. The zone of contribution is the entire flow system that supplies water to the well, including in this case a large portion of the zone of influence.

Figure 7-6 presents the influence of fractures on a pumping well that has been placed at the intersection of two fractures in a fractured bedrock aquifer. This well location takes advantage of the higher permeability and storage provided by the fracture zone. Flow to the well is controlled by the distribution and degree of interconnection that exists between fractures and by the variations in aquifer recharge due to rainfall.

A 3-day pump test as conducted on the Parella well (W-30) to determine the aquifer characteristics. The extent of the capture zone was calculated for well W-30 and is detailed in Section 4.0 of this report.

7.7.10 Time of Travel (TOT) of the Dissolved Solvent

Time of travel is a term for the maximum time for a groundwater contaminant to reach a well. The transport of a contaminant through the soil is determined by the physical and chemical properties of both the subsurface material and the contaminant.

For most well fields, particularly those where flow velocities are relatively high, advection accounts for most of the movement of contaminants toward the well(s). In aquifers where the velocities are high, it is likely that a contaminant would travel quickly toward the well(s).

In fractured bedrock aquifers with very high flow rates, fractures act as either open or closed channels. Travel times are extremely rapid in geologic settings with such high flow velocities under peak conditions for only short periods of maximum recharge. For the entire flow system, these velocities are in terms of hours to days or weeks, rather than the years and multiples thereof characteristic of laminar flow in porous, sandy aquifers.

Groundwater flow rates in limestone, sandstone and shale are often high when these rocks form fractured bedrock aquifers, i.e., rock with cracks in it that channel the groundwater. Groundwater flow rate is proportional to the porosity or amount of spaces in the rock or soil. Sand has a high primary porosity with many spaces between the sand grains. Fractured shale has a low primary porosity (few spaces between the grains of the rock); however, the secondary porosity of the fractures increases the overall porosity. As the spaces become smaller, groundwater flow accelerates under the same gradient. The combination of a high groundwater gradient, a bedrock fractured aquifer and a pumping well can result in extremely high groundwater flow rates down major fractures.

7.7.11 Degradation of Groundwater Contamination in the Bedrock

The principal contaminant on site is tetrachloroethylene. It is apparent that after reviewing the site data that tetrachloroethylene has not degraded significantly during the duration of the entire site investigation. The concentrations of tetrachloroethylene detected during the 1992 groundwater sampling events are consistent with the concentrations detected during the initial phases of the site investigation conducted in the early 1980's. The presence of trace amounts of trichloroethylene, 1,1-dichloroethylene, and vinyl chloride is more likely attributed to impurities in the solvents that were supplied to General Switch. Since the tetrachloroethylene was used by General Switch for degreasing metal parts, impurities would not affect the overall effectiveness of the degreasing operation.

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ADDITIONAL REFERENCES ARE CONTAINED AT THE END OF THE FOLLOWING SUPPLEMENT TO SECTION 7, ENTITLED "TERMINOLOGY FOR DNAPL SITES."

The following terminology is intended to provide a consistent set of terms for use in discussions of investigations and remediation at DNAPL sites. The use of this terminology may avoid some of the confusion that commonly occurs when people from different backgrounds (hydrogeology, chemistry, reservoir engineering, regulatory, legal) attempt to discuss DNAPL issues or problems. This set of terms will probably warrant some revision after it is subjected to use in a multidisciplinary context.

Terminology for DNAPL Sites

CUTOFF WALL - A low-permeability vertical barrier placed around a zone of contamination. There are various types of walls, such as bentonite-soil slurry walls, concrete panel walls, plastic membrane walls, and sealable-joint steel sheet piling walls. The wall may be keyed into an aquitard (keyed wall) or not keyed (hanging wall).

DNAPL - An acronym for a dense nonaqueous phase liquid. It is synonymous with dense immiscible-phase liquid. The term has sometimes been used to refer to dissolved- or aqueous-phase contaminants, but to avoid confusion, the term DNAPL should be reserved exclusively for the nonaqueous phase liquid.

DNAPL ENTRY LOCATIONS - Locations where DNAPL has entered the subsurface by way of leaks, spills, discharges or any other escape.

DNAPL REMOVAL (or IMMISCIBLE-PHASE MASS REMOVAL) - Refers to removal of immiscible-phase residual, lens, or pools by technologies such as by free-phase pumping, water flooding, enhanced solubilization, vapor extraction or air sparging.

DNAPL SITE - A site where an immiscible liquid with a density greater than water has entered the subsurface and exists below the water table as a separate residual or immiscible phase.

DNAPL ZONE CONTAINMENT or IMMISCIBLE-PHASE ZONE CONTAINMENT - Refers to measures taken to control or prevent migration of dissolved-phase contaminants and immiscible-phase liquid (DNAPL). Plume control and DNAPL zone containment may involve some of the same remedial actions such as pumping well networks or drainage trenches, but the are generally applied in different areas.

FREE-PHASE LIQUID - Immiscible liquid existing in the subsurface under positive pressure. Free-phase liquid can flow into a well under the influence of gravity and can be mobilized by hydraulic forces.

GROUND-WATER REMEDIATION - A very general term referring to any or all activities taken to improve ground-water quality or control the spread of ground-water contamination, such as plume capture, or control, DNAPL removal or ground-water restoration.

GROUND-WATER RESTORATION - Refers to the removal of subsurface contamination to the degree necessary to achieve appropriate cleanup levels which protect public health and the environment.

GROUND-WATER ZONE - The zone below the water table or free water surface.

GROUND-WATER ZONE IMMISCIBLE PHASE - Immiscible phase in either the residual or free-phase state, present below the water table. Ground-water zone immiscible phase is particularly important at DNAPL sites because it is generally the primary cause of plumes of dissolved-phase chemicals. Permanent restoration of ground-water quality at DNAPL sites generally requires removal of essentially all the mass of ground-water zone immiscible phase.

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IMMISCIBLE-PHASE ZONE or DNAPL ZONE - That portion of a site where immiscible-phase liquid exists as residual or free phase in the subsurface. This zone will also include chemical mass in the dissolved and sorbed phases. The immiscible-phase zone usually has immiscible-phase liquid both above and below the water table.

IN SITU IMMISCIBLE-PHASE DESTRUCTION - Refers to the destruction of DNAPL residuals, lens, or pools in situ by means of chemical or microbiological processes.

IN SITU IMMISCIBLE-PHASE SOLIDIFICATION - Refers to the immobilization of DNAPL residual, lens, or pools by physicochemical processes that solidify the DNAPL within the geologic medium, thereby preventing spread and/or dissolution of DNAPL in ground water.

LENS - A zone of free-phase liquid that rests on lower permeability strata of limited areal extent. A lens is a small perched pool. A "pool" and a "lens" are different only in scale.

PERMEABLE REACTION WALL - Is similar to a cutoff wall, but the wall is relatively permeable to allow unimpeded ground-water flow. The wall is partially constructed from reactive materials to destroy and/or sorb contaminants. A permeable reaction wall may be a passive alternative to pump-and-treat for plume control.

PLUME - The zone of ground-water contamination that exhibits dissolved-phase contaminants at concentrations above some specified concentration level, such as a drinking water limit, detection limit, or background. The volume of the subsurface that the plume encompasses includes the subsurface contaminant source (residual, lens, and pools of DNAPL). To avoid confusion, the term "plume" should not be used to refer to a pool of free-phase immiscible liquid. Plume removal refers to the removal of the dissolved-phase mass. DNAPL removal refers to removal of the immiscible-phase liquid.

PLUME CONTROL (or PLUME MIGRATION CONTROL) - Refers to measures taken to cutoff or control dissolved-phase contamination so that the advance of the plume is restricted, thereby reducing or eliminating the risk to receptors that would otherwise be impacted by dissolved-phase contaminants transported by ground water.

PLUME REMOVAL - Removal, generally, by pump and treat, of all or nearly all of a plume (except for dissolved-phase contamination in the immediate vicinity of DNAPL residuals, lens, or pools). Typically, at DNAPL sites, if the plume is removed and the pump-and-treat system is shut down, the plume will reestablish itself by dissolution of DNAPL located below the water table. Therefore, plume removal at DNAPL sites without containment (or removal) of the DNAPL zone will not achieve "ground-water restoration."

POLISHING - Polishing is a cleanup phase applied to remove or destroy dissolved, sorbed, or residual contaminants rather than immiscible-phase liquids in lens or pools. To achieve "ground-water restoration", an aquifer would generally need to be polished after other remedial measures have been taken to remove nearly all the mass of immiscible-phase (DNAPL) liquid.

POOL - A zone of free-phase immiscible liquid that resides at the bottom of an aquifer. A pool rests on top of an aquitard. A pool may be in an immobile state or it may be in a state of motion, depending on whether or not free-phase liquid is being added to the pool.

POOL or LENS REMOVAL -The removal of the free phase or otherwise movable immiscible liquid from a pool or lens by direct DNAPL pumping or enhanced mobilization. Such removal leaves a residual mass of immiscible-phase liquid under capillary tension.

PUMP-AND-TREAT - This term is reserved for the removal of water containing dissolved-phase contaminants by means of wells or trenches. The recovered water is treated at the surface.

RESIDUAL - Immiscible-phase liquid held in the pore spaces or fractures by capillary tension (negative immiscible-phase pressure). The immiscible-phase liquid in residual form cannot be mobilized by reasonable hydraulic forces.

SOURCE - This is a term meaning different things to different people. To some lawyers and administrators, source refers to surface or very near surface causes or potential causes of ground-water contamination, such as drums, sludge or contaminated surface soil. To scientists and engineers operating in the context of conceptual models of DNAPL in the subsurface, a source of most significance is generally a mass of immiscible-phase liquid (residual, lens, or pool) located below ground surface. To avoid confusion, the term "source" should be used with specific modifiers, such as below water table DNAPL source, surface source, etc.

VADOSE ZONE - The zone above the water table which may contain saturated or partially saturated sediments.

VADOSE ZONE IMMISCIBLE PHASE - Immiscible liquid present above the water table, generally as residual but occasionally as lenses of free-phase liquid perched on lower permeability strata.

VAPOR EXTRACTION - Refers to removal of DNAPL residuals, lenses, or pools by passage of air through vadose zone resulting in volatilization and gas transport.

VAPOR PLUME - Zone of vapor in the vadose zone.

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Appendix B

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SECTION 8

CONTENTS

8.0 SUMMARY OF FINDINGS AND CONCLUSIONS

This section presents a summary of the findings, conclusions and recommendations.

8.1 GEOPHYSICAL SURVEYS

Geophysical surveys are discussed in detail in Section 2 and results of the surveys are presented in Appendix 2.

8.1.1 Fracture Trace and Structure Survey

A fracture trace and structure survey was performed to determine the location and frequency of bedrock structures that could potentially transmit contaminated groundwater. The description of the geophysics investigation is included in Section 2 of this report.

The aerial photograph review was conducted prior to the surface geophysical investigation in order to identify possible subsurface structures that would be further investigated with the geophysics. The aerial photograph review identified several linear land surface features which could be indicative of subsurface fracture zones. The primary linear land surface features trend northeast to southwest, with one possible linear feature trending north to south.

The surface geophysics investigation, which was performed with electromagnetic (EM) survey equipment, targeted the areas identified during the aerial photograph review. The results of the EM survey showed good correlation with the aerial photograph review. The linear surface features were also identified during the EM survey.

The most important indication of subsurface features occurs between the residence at 320 Highland Avenue and the General Switch building. The NE to SW trending features were identified during aerial photograph review and the surface geophysics investigation. These suspected subsurface features are important because these features could be fractures that transmit groundwater from the General Switch area to well W-30 (Parella).

Of all the site wells, W-30 is the only well that has been identified as containing free product. This is significant because there are other wells closer to General Switch (i.e., MW-202, MW-2, MW-17, MW-18) which do not contain free product. This fact suggests that free product is migrating in preferential pathways, such as fractures in the bedrock, which would account for free product being detected in well W-30 but not in MW-202. As determined by step drawdown tests, well W-30 can sustain 2 gpm, while MW-202 cannot sustain even ½ gpm. This fact suggests that MW-202 does not intersect the same fracture as well W-30 and therefore further supports the contention that the free product is migrating along discrete fractures in the bedrock.

8.1.2 Borehole Logging

Borehole geophysical logging was performed on wells MW-202, MW-203, MW-204, MW-207, W-8 (Osbourne), W-17 (Barry), W-30 (Parella), W-31 (Electra), W-32 (Stout), W-33 (Contel) and MW-12, and soil borings SB-1, SB-5 and SB-11 in order to obtain additional information regarding subsurface conditions.

From the borehole logging it is possible to identify potential zones of fractures and lithology changes. In addition, it is possible to evaluate and correlate strata from areas of known lithology to areas that have not been logged. For example, there is a group of distinct sandstone layers that apparently slope into the hillside from the southeast (MW-204 and MW-203) to the northwest (W-17 and W-8) at a 6.2 degree northwest dip.

From these data, it is possible to determine that the bedding planes of the bedrock slope into the hillside and therefore contamination may be migrating along the bedding plane, which would give it the appearance of flowing upgradient. The presence of free product tetrachloroethylene in well W-30, which is sidegradient of General Switch, may be an indication that contamination is flowing along fractures or bedding plane separations.

Although zones of high conductivity values have been identified in the geophysics logs down the profile of the bedrock, it is not possible to evaluate whether these zones transmit appreciable amounts of water or high concentrations of contamination. Dissolved ions in the groundwater, such as calcite, would increase the conductivity of the water thus producing high readings that were not necessarily indicative of contamination. From the calcite infilling of fractures, as observed in the rock cores, it is apparent that calcite is present in the groundwater. The bladder sampling and packer tests were conducted to evaluate the quality and quantity of water transmitted through the potential fracture zones.

8.2 PHYSICAL CHARACTERISTICS OF THE SITE

A detailed discussion is presented in Section 3.

The stratigraphy of the site is a silty glacial till overlaying a sandstone and shale formation (the Austin Glen Series).

From profiles of the soils at the site, it can be noted that the soil horizons of the Washington Heights section of the Town of

Wallkill belong to the Mardin gravelly silt loam series (Reference 3: Orange County Soil Survey). The Mardin soils are formed from a gravelly, sandy silt glacial till which in turn is derived from the sandstone, shale and slate of the bedrock of this area. The unconfined till lies on the Austin Glen Grit and Shales.

The building and parking lot on the General Switch site sit upon fill, which is composed in part of reworked till that contains cobbles. The thickness of the fill varies from a few inches on the north of the building, where the footings of the building rest on native glacial till, to 10 to 12 feet in the parking lot.

On top of the shale and sandstone bedrock, there is a layer of glacial till that ranges from 7 to 108 feet thick under the site. This glacial till has accumulated across the hillside of Washington Heights on top of the shale and sandstone bedrock. The topography of the site follows the general trend of the top of bedrock under the site and decreases in elevation toward the wetlands and down Highland Avenue to the northwest.

There are two soil types of glacial till under the property. An orange-brown glacial till consisting of fine sand and silt is generally found near the top of the soil profile. The till tends to become more clay-rich and the boulders increase in abundance with depth. Below this brown till is a gray clay till layer containing abundant fractured shale fragments that overlies the fractured shale bedrock. In the soil borings drilled during implementation of the Fred C. Hart study and the Shakti site investigation, the glacial till in the General Switch area was found to be fairly consistent in color and texture.

The unconsolidated sediments at the site are underlain by a shale and sandstone formation known as the Austin Glen Grit and Shale Series. The Austin Glen Grit and Shale (the Shale) consists of interbedded massive sandstones grading with increasing micaceous minerals through siltstone and graywackes to thinly-bedded fissile shales. The strike of bedding for the Austin Glen Series is northeast-southwest and the regional dip is 16-40° northwest, observed in local outcrops on Industrial Place that cut across the southern perimeter of the study area.

8.3 ROCK CORE ANALYSIS

Rock cores were obtained from bedrock wells MW-202, MW-203, MW-207, MW-12/soil boring SB-15, MW-14/soil boring SB-18, MW-15/soil boring SB-16, soil boring SB-1, soil boring SB-5 and soil boring SB-11. A full description of the rock core analysis is presented in Section 3.

Rock cores were obtained from selected soil borings and bedrock wells to confirm the depth to bedrock and obtain additional information regarding the bedrock.

For the purpose of this site investigation, the most important observations obtained from the rock cores are such characteristics as lithology, the degree of fracturing and orientation of fractures in the residential wells and adjacent to contamination hot spots. The location of each fracture was recorded on a core log to be able to fully evaluate the extent of fracturing. The type of fracture (bedding plane separation, shear, cleavage), fracture spacing, roughness, planarity, infilling/staining material, and angle of dip were recorded. In the event that the fracturing was too extensive, the location of the zone was identified and labelled as a highly fractured zone.

Evaluation of the rock cores indicates that the shale bedrock beneath the site is highly fractured. The fractures, which are more frequent near the surface of the bedrock, become less frequent with increasing depth. As the overburden stress increases with depth, the rock is less likely to develop fractures, and existing fractures would tend to be closed.

There are apparently water-bearing fractures as evidenced by the smooth rock surfaces of many of the fractures and numerous fractures that are filled with calcite crystals or iron staining. The great number of water-bearing fractures in the rock cores indicates that there may not be preferential transport through one set of fractures or through fractures at only certain depths. As a result of the high frequency of interconnected water-bearing fractures, it is not possible to isolate specific zones of contaminant transport at particular depths in the bedrock.

In conclusion, analysis of the rock cores shows that the bedrock is highly fractured, especially at the top of bedrock and less so with increasing depth. The fractures are primarily in the horizontal plane; however, there is a high percentage of fractures in the vertical plane as well. This conclusion is to be expected for a fissile shale. The varying fracture orientations indicate that liquids will readily flow both laterally and vertically. The vertical migration of contamination will be limited by the degree of fracturing at depths of greater than 100 feet below ground surface. The rock cores show that the degree of fracturing is greatly reduced at the bottom of the 200-series wells, which are approximately 100 feet deep.

8.4 EXTENT OF SOIL CONTAMINATION

A detailed description of the extent of contamination is presented in Section 5. A laboratory analytical data summary for all samples is presented in Appendix 5.

8.4.1 Area TP-6

TP-6 is the area in the southern corner of the General Switch parking lot at the top of the slope and at the base of the slope at MW-3, MW-16 and MW-203.

Soil samples (test borings T-1 through T-4) were collected from the parking lot at the top of the slope during the soil investigation performed by Hart. All soil samples collected from the four test borings in this area show that tetrachloroethylene contamination does not exceed 20 ppm.

During the recent investigation performed by Shakti, four soil borings (SB-1 to SB-4) were conducted around existing well MW-3 at the base of the slope below the parking lot. Soil samples were collected at 2-foot intervals to the top of bedrock, which was encountered at approximately 10 feet below grade. None of the soil sample results exceeded 1 ppm.

None of the soil samples were found to have tetrachloroethylene concentrations in excess the 50 ppm provision of the Consent Order.

8.4.2 Area TP-D

During the Hart site investigation, soil samples were taken from test borings T-5 through T-14 in area TP-D. Soil samples were analyzed in the field using a portable gas chromatograph.

With respect to contamination in the vertical direction in this area, the higher concentrations were found at depths of 0 to 12 feet, with the highest concentrations generally at depths of less than 10 feet. Field determined concentrations in samples taken at depths of 12 to 17 feet were in the range of approximately 5 to 16 ppm.

With respect to the lateral extent of tetrachloroethylene contamination in this area, the highest concentrations were found in test borings T-7, T-8, T-9, T-10 and T-11, at levels of up to approximately 200 ppm with the Photovac and greater than 1,000 ppm with the OVA. The lowest concentrations were found in test borings T-5, T-8, T-12, T-13 and T-11, in a range of less than 1 ppm to approximately 20 ppm. These test borings define the lateral extent of tetrachloroethylene contamination in this area.

Although the field analysis performed by Hart showed tetrachloroethylene contamination in the range of less than 1 ppm to approximately 200 ppm, the field results vary from the OVA by one to two orders of magnitude.

In order to verify the field results, additional sampling was performed by Shakti in 1992.

During the site investigation performed by Shakti, soil samples were collected from five soil borings conducted in area TP-D (located in the parking lot adjacent to the rear loading dock). The soil samples, which were collected from the ground surface to the top of bedrock, were analyzed in the laboratory in order to verify previous field results.

The soil sample collected from 6-8 feet deep from soil boring SB-12 (MW-18) contained 50 ppm of tetrachloroethylene. In addition, the soil sample obtained immediately above bedrock at a depth of approximately 22-24 feet at the loading dock contained tetrachloroethylene at 370 ppm. Thus, it appears that solvent in the area of TP-D reached the top of bedrock. Samples from the surrounding soil borings contained concentrations of tetrachloroethylene below 50 ppm, indicating that the tetrachloroethylene contamination at TP-D has been successfully delineated.

8.4.3 Area TP-A

During the Hart site investigation, soil samples were taken from test borings T-15 through T-20 in area TP-A (back door of General Switch). Soil samples were analyzed in the field using a portable gas chromatograph.

There is contamination in the vertical direction in this area to a depth of at least 10 to 12 feet. The top of bedrock is approximately 15 feet deep. The highest concentrations were found in test borings T-15, T-18, T-17 and T-20, at levels of up to approximately 200 ppm with the Photovac and greater than 1,000 ppm with the OVA. Test boring T-19 had a maximum concentration of approximately 5 ppm and all three concentrations in T-18 were less than 1 ppm. It appears that test boring T-19 defines the lateral extent of tetrachloroethylene contamination parallel to the building in this area.

In order to verify the field results, additional sampling was performed by Shakti in 1992. During the Shakti site investigation, soil samples were collected from five soil borings conducted in area TP-A. The soil samples, which were collected from the ground surface to the top of bedrock, were analyzed in the laboratory in order to verify previous field results and to determine soil quality at the top of bedrock. The concentrations of tetrachloroethylene in the laboratory samples taken from TP-A varied from the highest in SB-6 to non-detectable in SB-5.

The highest concentrations of tetrachloroethylene were detected in SB-6. The sample collected from 2-4 feet contained 5,500 ppm of tetrachloroethylene; however, the sample from 8-10 feet contained less than 1 ppm. OB-2 was the boring with the next highest concentrations. A concentration of 950 ppm was detected within the top 2 to 4 feet of soils in OB-2, and a concentration of 360 ppm was detected at the top of bedrock. Both samples from OB-9 also exceeded 50 ppm. The soil samples from SB-7, SB-13 (MW-17), OB-6 and OB-7 showed less than 0.2 ppm of tetrachloroethylene, indicating that the tetrachloroethylene contamination at TP-A has been delineated.

8.5 WETLANDS SURFACE WATER AND SOIL SAMPLING

Discussions on wetlands surface water and soil sampling are presented in Section 2. Laboratory analytical data for these samples are presented in Appendix 5.

Two sediment samples, designated as WET-003 and WET-004, were collected from the southern side of the wetlands area and along Industrial Place Extension. These samples were analyzed by a laboratory for volatile organics. Laboratory analysis indicated that sample WET-003 contained no detectable levels of tetrachloroethylene. Sample WET-004 contained 0.098 ppm of tetrachloroethylene.

Laboratory results from soil boring SB-20, which was completed as MW-9, indicate tetrachloroethylene concentrations range from non-detectable to 0.100 ppm. At a depth of 10 feet to a depth of 12 feet, where bedrock was encountered, the concentrations increased from 1.0 to 1.3 ppm. Subsequent sampling of MW-9 indicated that the groundwater has been impacted by tetrachloroethylene contamination.

The presence of tetrachloroethylene in sediment sample WET-004 obtained from the wetlands, coupled with its presence in the soil samples obtained from SB-20/MW-9, indicates the existence of tetrachloroethylene in the unconsolidated soils above the bedrock.

Soil Contamination in Wetlands

Contamination may be present in the soil in the wetlands, not because of surface discharges, but through groundwater transport and adsorption. Remote areas of the wetlands, such as at MW-9 and sample WET-003, have low-level tetrachloroethylene contamination and it is unlikely that tetrachloroethylene was spilled in remote areas or that there was overland flow of tetrachloroethylene. The water table fluctuation in the wetlands is well known and has been documented. Some of the wells in the wetlands, such as MW-11, have water only certain times of the year. Likewise, there is standing surface water during the wetter times of the year.

The groundwater as far southeast as MW-9 is known to be contaminated with 2,700 ppb of tetrachloroethylene. During upward water table fluctuations, contaminated water comes in contact with the wetlands soil, which is probably very high in clay and organic material. Organic or clay rich soils have very high surface area densities and are chemically active; these factors result in an increased number of chemical bonding sites on the soil particle surfaces, which increases the amount of adsorption that occurs.

There are seasonal fluctuations in the surface water and groundwater levels in the wetlands which most likely causes deposition of tetrachloroethylene in the soil. Since the contaminant concentration in the sediment are very low (none detected and 0.098 ppm), no further investigation is recommended for the wetlands.

8.6 SEWER SAMPLING

A detailed description of the sewer sampling is included in Section 2. Laboratory analytical data are presented in Appendix 5.

Water and sediment samples were collected from the sanitary and industrial sewer line along Industrial Place, Industrial Place Extension and Highland Avenue. The sewer water and sediment samples were analyzed by the laboratory for volatile organics. During sampling, it was observed that there was no sediment build-up in the sewer lines, except for the minor amounts found in the sewer line at the intersection of the General Switch outfall into the Middletown sewer line.

Based on the laboratory analysis of sewer water and sediment samples, tetrachloroethylene is present in both the water and sediments running through the sewer line connected to the City of Middletown Sewage Treatment Plant. Since tetrachloroethylene is a commonly used solvent, the source or sources of tetrachloroethylene could potentially be any of the industrial customers discharging to this line over the course of their operating history.

The increase in tetrachloroethylene concentrations at particular junctions in the sewer line could represent accumulations over time or it could represent an additional contribution by a facility connected to the line at this point. Based on the increase of tetrachloroethylene concentrations at the manhole located 40 feet south of Lubricants, Inc. (SEW-04), it is probable that there are one or more sources down stream from General Switch on Industrial Place Extension that are contributing to the concentrations of tetrachloroethylene in the sewer line along Industrial Place Extension.

The sample (SEW-03) taken at the intersection of Highland Avenue and Park Avenue did not contain any detectable concentrations of tetrachloroethylene.

8.7 EXTENT OF GROUNDWATER CONTAMINATION

Free product tetrachloroethylene was detected only in well W-30 (Parella) during field activities conducted at the General Switch site. The complete groundwater investigation details are contained in Section 5. Laboratory analytical data for groundwater sampling are presented in Appendix 5.

8.7.1 Bladder Sampling

Bladder sampling was conducted on wells MW-202, MW-203, MW-207, W-1 (Perez), W-8 (Osbourne), W-17 (Barry), W-18 (Ruppert), W-30 (Parella), W-31 (Electra), W-32 (Stout) and W-33 (Contel).

The bladder sampling of W-1 (Perez), W-8 (Osbourne), W-17 (Barry), W-18 (Ruppert), W-30 (Parella) and W-32 (Stout) showed that there are minor variations in the contaminant concentrations at different depths in the wells. The variations are, however, typically within one order of magnitude. Tetrachloroethylene is expected to sink within a water column because its specific gravity is greater than that of water. The bladder sampling showed that the concentrations of tetrachloroethylene were not greatest at the bottom of each well as was expected, instead the concentrations are relatively uniform throughout the water column, except for the free product DNAPL detected in the bottom of well W-30 (Parella).

In well W-30 the highest tetrachloroethylene concentrations were detected at approximately 62 feet below grade, which indicates that there may be a major fracture at that depth, which is supplying more highly contaminated water to the well. The caliper and conductivity logging, performed as part of the downhole geophysical study, shows that there is a suspected fracture zone at this depth that has a slightly elevated conductivity (high conductivity measurements can be indicative of water bearing or contamination bearing layers). The bladder sampling results and the geophysics data support the contention that there are discrete fracture zones that carry contaminated water.

In well W-18 (Ruppert) there were elevated concentrations of tetrachloroethylene at depths of 36 feet, 96-126 feet and 146 feet below ground surface, which indicates that there may be several distinct fracture zones in well W-18. If the correlation of the bladder sampling and geophysics in well W-30 is accurate, it can be applied to other wells, such as W-18.

Based on the foregoing, it is apparent that contamination may be migrating along discrete fractures. The bladder sampling has shown that although there are zones of contamination, the difference from zone to zone is typically within an order of magnitude. This suggests that all fracture zones should be pumped equally to recover the contaminated groundwater. If there was significantly higher contamination detected in only one zone, it would warrant pumping from only that zone. Since this is not the case, recovery wells will not have to be packed off when pumping.

8.7.2 Glacial Till

The first phase of groundwater sampling that encompassed the wells screened in the unconsolidated sediments indicates that the shallow aquifer has been impacted by tetrachloroethylene. The highest concentrations of the plume in the glacial till are centered on MW-5, MW-4, MW-3 and MW-16, all of which are south of the General Switch parking lot. The tetrachloroethylene concentrations in this portion of the plume range from 41,000 to 8,300 ppb. TP-A, the area adjacent to the rear door area of General Switch, also has elevated levels of tetrachloroethylene at 1,000 ppb. The wells on the periphery of the plume, namely MW-1, MW-2, MW-6, MW-7 and MW-10, have tetrachloroethylene concentrations ranging from 2.2 to 57 ppb. Wells MW-8 and MW-11 were dry at the time of sampling.

The groundwater results indicate that the plume is concentrated in the area of TP-A and the area south of the parking lot, however all wells sampled are above the USEPA's groundwater MCL of 1 ppb for tetrachloroethylene.

The second phase of groundwater sampling for the shallow wells confirms that the tetrachloroethylene plume is similar to that indicated by the first phase of sampling. The highest concentrations of the plume are centered on MW-4, VES-2 and MW-3, all of which are south of the General Switch parking lot. The tetrachloroethylene concentrations in this area range from 26,000 to 11,000 ppb. TP-A, the area adjacent to the rear door of General Switch, also has elevated levels of tetrachloroethylene at 1,500 ppb. The wells on the periphery of the plume, namely MW-1, MW-2, MW-6, MW-7 and MW-10, have concentrations ranging from 5 to 120 ppb. Wells MW-5, MW-8 and MW-11 were dry at the time of sampling. MW-9, which was not sampled during the first or second events, was sampled in May, 1993 and the concentration of tetrachloroethylene in MW-9 was 2,700 ppb. The tetrachloroethylene plume extends from the General Switch building into the wetlands.

The groundwater results indicate that the plume is concentrated from TP-A, through the southern corner of the parking lot to Industrial Place Extension. As with the first phase of sampling, the plume is not delineated.

8.7.3 Shallow Bedrock

Shallow bedrock wells MW-12, MW-13, MW-14 and MW-15 are located along Highland avenue adjacent to the Parella (W-30), Stout (W-32), Contel (W-33) and Barry (W-17) residential wells, respectively. The first round of groundwater sampling from these four wells showed that there is tetrachloroethylene in all of these wells. The highest concentrations of tetrachloroethylene were at MW-12 (140 ppb) and MW-13 (130 ppb), with lesser concentrations at MW-14 (12 ppb) and MW-15 (4 ppb). From this data it is apparent that the plume extends from the residence at 320 Highland Avenue outward toward the residence at 309 Highland Avenue. The southwest edge of the plume is most likely close to MW-15.

The second round of groundwater sampling from these wells showed a change in the location and concentration of the plume. MW-12 and MW-14, screened at the top of bedrock adjacent to Parella (W-30) and Contel (W-33) wells, maintained tetrachloroethylene concentrations of 280 ppb and 140 ppb, respectively, which is consistent with the first round. The concentration of tetrachloroethylene in MW-13, adjacent to well W-32 at 316 Highland Avenue, increased from 130 ppb to 2,900 ppb. MW-15 also showed an increase from 4 ppb to 18 ppb. The data indicates that the plume has moved more to the southwest and has increased in concentration. This conclusion, although evident from the data, is difficult to explain because if the pump test caused movement of the plume, the movement should have been back toward, not away from, the pumping well (W-30).

The shallow wells along Highland Avenue indicate that the shallow bedrock at the western part of the plume is not the principal avenue of migration for tetrachloroethylene. The deep bedrock wells at Parella (W-30), Stout (W-32), Contel (W-33) and Barry (W-17) generally have higher levels of contamination than the shallow bedrock wells. There is correlation between the contaminant concentrations of deep and shallow bedrock wells, and it is therefore not essential that the extent of tetrachloroethylene contamination be fully delineated in the shallow bedrock wells as long as the extent of contaminated in the deep bedrock aquifer is defined.

8.7.4 Deep Bedrock

The first phase of groundwater sampling that encompassed the deep residential and monitoring bedrock wells indicates that the deep aquifer has been impacted by tetrachloroethylene. The highest tetrachloroethylene concentration of the plume was detected in the Parella well (W-30) at 150,000 ppb, which is the solubility of tetrachloroethylene in water at 25 degrees C according to the Handbook of Environmental Data on Organic Chemicals. The concentration of tetrachloroethylene at its solubility limit is consistent with the presence of free product. The plume extends linearly from this hot spot west towards Ruppert (W-18) well (8,200 ppb) and east towards MW-203 (13,000 ppb). The outer edges of the plume are characterized by Contel (W-33) well (420 ppb), MW-204 (204 ppb), the General Switch (W-30-2) well (21 ppb), Electra (W-31) well (49 ppb), Osbourne (W-8) well (9 ppb) and Knapp (W-14) well (3.7 ppb). Tetrachloroethylene was not detected in the Perez (W-1), Radivoy (W-36), Cornelius (W-7), Gilbert (W-11), Wood (W-13), Van Pelt (W-15), Holmes, Rasmussen (W-19) and Petruzzio (W-34) peripheral wells. These peripheral wells define the extent of the plume to the north and west.

The second phase of groundwater sampling of the deep bedrock wells indicates that the tetrachloroethylene contamination levels decreased from those detected during the first groundwater sampling event for most of the wells. The highest tetrachloroethylene concentration of the plume was detected in MW-202 at a concentration 9,600 ppb. Other significant tetrachloroethylene concentrations were detected in Parella (W-30) well (3,700 ppb), Contel (W-33) well (3,100 ppb), Ruppert (W-18) well (1,800 ppb), MW-204 (1,300 ppb) and MW-203 (1,100 ppb).

The periphery of the plume is characterized by the General Switch (W-30-2) well (38 ppb), Perez (W-1) well (4.9 ppb), Electra (W-31) well (110 ppb), Wood (W-13) well (2.7 ppb) and Petruzzio (W-34) well (1.4 ppb). Tetrachloroethylene was not detected in the Radivoy (W-36), Cornelius (W-7), Gilbert (W-11), Osbourne (W-8), Knapp (W-14), Holmes, Rasmussen (W-19), Robaina (W-26) and Nixdorf wells.

From the time of the first sampling event to the time of the second event, well W-34 became slightly contaminated, well W-33 and MW-204 became more contaminated, and wells W-30 and W-18 became much less contaminated. This indicates that the direction of the plume migration shifted from being toward the west to being toward the southwest.

Although there was slight migration of the plume, the extent of contamination in the deep bedrock aquifer, based on the two rounds of groundwater sampling discussed above, is limited to an area from MW-203 to W-18. The contaminated groundwater plume appears to have a linear shape which trends east to west in a 150-foot-wide zone approximately 700 feet long. The wells on the northern periphery of the plume, such as Cornelius (W-7), Wand (W-22), Radivoy (W-36), Gilbert (W-11) and Van Pelt (W-15), accurately define the upgradient extent. The wells on the south and southeast sides of the plume are contaminated and therefore it is not possible to determine the southern or southeastern extent of the plume. The west side of the plume has been delineated, because the wells at Rasmussen (W-19) and Robaina (W-26) are clean.

8.7.5 Groundwater Plume Delineation

Groundwater sampling results indicate that the plumes in the unconsolidated overburden, the shallow bedrock and the deep bedrock have not been adequately delineated to the south-southeast. Further discussion on plume delineation is presented in Section 8.11.

8.8 HYDROGEOLOGY

The full description of the hydrogeology is presented in Section 4.0.

8.8.1 Slug Tests

Slug tests have been performed on the shallow unconsolidated monitoring wells installed into the glacial till and fill material. The slug test results were used to determine hydraulic conductivity of the unconsolidated sediments. The Bouwer and Rice method was used to evaluate slug test data for the unconfined fill and glacial till aquifer.

The results indicate that hydraulic conductivity values of the till range from 0.1069×10^{-4} feet per minute in MW-11 to 19.81×10^{-4} feet per minute in MW-3, with a geometric mean of 0.8669×10^{-4} feet per minute. The results indicate that there is not a consistent difference in hydraulic conductivity between the glacial deposits and the imported fill. This is to be expected because both till and imported fill, which is reported to be local reworked till, are highly anisotropic due to the method of deposition.

8.8.2 Step Tests

Step drawdown tests were performed on select deep bedrock residential wells and deep bedrock monitoring wells to determine the optimum yield of wells. The step tests were also used to evaluate drawdown and the degree of hydrogeologic connection between various observation wells.

The results of the step-drawdown tests provided confirmatory data for evaluating the ability of the wells to sustain optimum pumping rates. The sustainable yields of residential wells ranged from 2 gpm in wells W-8 (Osbourne), W-17 (Barry), W-18 (Ruppert), and W-30 (Parella) to 6 gpm in wells W-1 (Perez), W-31 (Electra) and W-33 (Contel). The bedrock monitoring well yields ranged from less than ½ gpm in MW-202 to greater than 15 gpm in MW-207. Drawdown data collected from the observation wells provided an indication of the radial influence of the tested wells on the bedrock aquifer system.

Based on the findings of the step drawdown tests, the optimum pumping rate and suitable observation wells were selected for the 3-day pump test on W-30.

8.8.3 Pump Test

The pump test was performed to determine the hydrogeologic characteristics of the bedrock aquifer.

The groundwater contour results indicate that the pumping of W-30 (Parella well) had a major effect over a large area of the study site. The pump test created drawdown in all of the monitored wells (with the exception of the anomalous measurements from MW-14), which indicates that the bedrock aquifer and unconsolidated sediment aquifer may be hydraulically connected. This is significant in that the site has been studied as having separate aquifers, primarily a deep fractured bedrock aquifer and a shallow water table aquifer. The drawdown observed in both aquifers indicates that pumping of a well penetrating the deep aquifer potentially draws water from the unconsolidated sediments possibly through leakage.

This was confirmed through evaluation of the time-drawdown data for the 3-day test, which indicates that the bedrock aquifer behaves similar to a leaky confined/semi-confined aquifer rather than a linear fractured bedrock. The time-drawdown data was analyzed by the Hantush-Jacob method. The curves were graphed and values were obtained for transmissivity (T) and storativity (S). The mean T obtained from the data is 0.0076 feet^2 per minute, and the mean S is 5.361 10^{-5}. From these results, a mean K value of 0.76 10^{-4} feet per minute and a mean velocity (Darcy) value of 0.489 10^{-5} feet per minute were computed.

The recovery data were analyzed by the residual-drawdown method developed by Theis. The curves were graphed and values were obtained for transmissivity: the mean T obtained from the data is 0.0098 feet^2 per minute. From these results, a mean hydraulic conductivity (K) value of 0.98 10^{-4} and a mean velocity (Darcy) value of 0.63 10^{-5} feet per minute were computed.

The mean hydraulic conductivity value for the unconsolidated aquifer (0.8669 10^{-4} feet per minute), as determined by analysis of the slug tests, is consistent with those determined by analysis of the drawdown and recovery phases of the 3-day pump test. The mean hydraulic conductivity values are similar, which may suggest that the bedrock and unconsolidated aquifers are not independent. However, the fractured shale bedrock aquifer and unconsolidated till aquifer are composed of vastly differing material, and therefore it is likely that the aquifers are independent.

The maximum, minimum and average capture zones for well W-30 were computed and have been plotted on the site map to show the potential area of influence for W-30 pumped at 2 gallons per minute. The minimum capture zone, which covers an area of approximately 7,400 square feet, does not influence the presently known extent of the contaminant plume.

8.9 PACKER TESTING

Packer tests are discussed in detail in Section 4 of this Report.

Packer tests were to be performed on wells MW-202, MW-203, MW-204, MW-207, W-8 (Osbourne), W-17 (Barry), W-30 (Parella), W-31 (Electra), W-32 (Stout), W-33 (Contel) and MW-12, which were logged by the down-hole geophysical methods. Wells MW-202, MW-203, MW-207, Contel (W-33) and Parella (W-30) were actually packer tested. The wells were packed at intervals that, based on the down-hole logging, were suspected to have fractures that could act as routes of transport for DNAPL or dissolved solvent.

The results of the initial packer tests of wells MW-202, MW-203, MW-207, W-33 and W-30 indicate that packer tests do not provide reliable information regarding the characteristics of water-bearing fractures in the bedrock monitoring and residential wells.

For the packer tests of MW-202 and W-30, the summed pumping rates for the packed intervals exceeded the total pumping rate for the entire well. For the packer tests of MW-203, MW-207 and W-33, dye was placed in each well above the upper packer during the packer testing and was observed in the pump discharge water. Based on the observation of geological leakage, the packer testing program was stopped and none of the other wells were tested.

The reliability of data obtained from the packer testing has been re-evaluated, since geological leakage was observed in all of the wells that were packer tested. It is apparent that packer testing does not provide data regarding the extent of fracture zones, the amount of water yielded by specific fracture zones or the concentrations of contamination travelling through the fractures.

The packer tests, although not providing data about specific fracture zones, do provide useful information regarding the overall site geology, namely, that the shale bedrock is highly fractured in both the horizontal and vertical directions. Upon review of the caliper logs of the deep residential wells, it is clear that the walls of the older residential wells are degraded. The rock cores for the deep bedrock monitoring wells were reviewed and the fracturing observed in the cores for each of the bedrock wells was in both the horizontal and vertical planes. These observations are consistent with the nature of the bedrock; it is a fissile shale that is highly fractured in many directions.

The results of the packer tests indicate that due to the fractured bedrock there may be vertical leakage in all of the wells tested. This fact combined with the caliper log data and the rock core analysis indicates that regardless of whether the packer was able to obtain a good seal, complete isolation of the suspected fracture zone will not be possible due to vertical leakage between interconnecting fractures.

In light of the foregoing, one additional conclusion that can be drawn is that groundwater flow in the bedrock is most likely through numerous minor fractures instead of several major fractures. This conclusion is supported by the evaluation of the W-30 bedrock well pump test data. A radial flow method for data evaluation was employed instead of a linear flow method, which indicates that the flow is probably through numerous interconnected minor fractures and not only major fractures.

8.10 PILOT STUDIES

The pilot studies conducted during implementation of the RSAMP are presented in section 6.

8.10.1 Soil Vapor Extraction Feasibility

The hot spot TP-A in the rear (north) of the General Switch site building was selected to investigate the feasibility of soil vapor extraction. The objective of this investigation was to determine if the volatile organic contaminants can be successfully removed by drawing a vacuum on the soil and providing sufficient air flow through the soil to mobilize and capture the soil vapor. The dense, consolidated glacial till and non-homogeneous overburden presented potential limitations upon the effectiveness of the available treatment alternatives for the site.

The vapor extraction well, VES-1, and a series of seven observation wells, OB-1 through OB-3 and OB-6 through OB-9, were installed in the area of the hot spot TP-A. For the test, a vacuum was drawn on VES-1 and the pressure drop was monitored in the observation wells and in groundwater monitoring well MW-17.

The relationship between the flow rate of the soil vapor withdrawal and the induced vacuum observed at the observation wells determines if an effective soil vapor extraction system can be utilized at the site.

The maximum effective radius of influence (MERI) associated with a particular flow rate is determined empirically from the pilot test data by plotting the logarithm of the observed induced vacuum measured in the observation wells versus the radial distance form the active vapor extraction well. For each of the flow rates during the test, the plot of the log of induced vacuum [Log (i.w.)] against radial distance from the extraction well VES-1 (feet) produced a straight line graph developed by a linear regression program. The point at which the line intersects the negative 1 logarithm value that corresponds to 0.1 i.w. is the MERI. The test results indicate that the MERI ranges from 16.3 to 21.4 feet with flow rates ranging from 10.47 to 39.24 cubic feet per minute (CFM)

The flow rate (CFM) was then plotted against the MERI (feet) and the point indicated on the curve at which the flow rate increases exponentially corresponds to the point at which the vacuum efficiency decreases due to vacuum dissipation by increased induced flow rate in the soil. The data indicates that the optimum soil vapor withdrawal rate 24 CFM occurs at a MERI equal to 20 feet.

Air samples were collected during the pilot study indicate that the tetrachloroethylene concentration in the soil vapor extracted ranged from 96 ppm to 1,293 ppm for Photovac analysis and ranged from 740 ppm to 1,887 ppm for Microtip analysis. The laboratory results were not available as of the date of this report.

The initial evaluation of the soil vapor extraction test data indicates that soil vapor extraction will be effective as a method of remediating this area of contamination. Soil vapor extraction can be effectively applied to TP-A. Dewatering would have to be implemented in conjunction with vapor extraction to maintain a thick enough unsaturated soil zone. A thick saturated soil zone would reduce the efficiency of the vapor extraction. A totally saturated soil zone would preclude the use of vapor extraction. Vapor extraction was proven to be feasible, other considerations must be accounted for prior to selection of a remedial technology. The remedial alternatives and the selected technology are presented in Section 9.0 of this report.

8.10.2 Air Stripper Feasibility

Water from all of the groundwater related activities was successfully treated through the progressive air stripper deployed on site.

The progressive system design, which is presented in Section 6.0, is similar to a conventional packed column air stripper, except the progressive air stripper is a series of air stripping lifts instead of a single air lift. The progressive system installed at General Switch consists of a series of ten air lifts. At the bottom of each air stripping lift, air is entrained into the water stream. The air bubbles up the vertical riser tube with the water stream and volatilizes the contaminant. At the top of the air lift, the water flows across into the next air lift, forming an air-water interface from which the contaminant-laden air rises into the air collection header.

Water pumped from wells was temporarily containerized in a 350-gallon equalization storage tank, which evens out peaks in the influent concentration. The water was pumped from the storage tank to the progressive system for primary treatment and then to imbiber bead filters for secondary treatment. The treated water was discharged to the sanitary sewage system after temporary storage on site. To enhance removal of the volatile organic compounds, treated water is recirculated through the air lifts. The average flow rate achieved during water treatment was approximately 4 gpm.

The air exhaust was passed through vapor phase activated carbon for treatment prior to discharge to the atmosphere.

Samples of the water were collected at several locations to document water quality. Water samples of the influent to the air stripper, the effluent discharge from the air stripper, the influent to the treatment plant (located approximately 3 miles from the General Switch site), and effluent from the plant into the Wallkill River (located adjacent to the plant) were collected. Water samples were analyzed for volatile organic compounds using the Photovac, with confirmatory samples analyzed by a laboratory.

Laboratory analytical results of the air stripper influent and effluent indicate that the progressive stripper system is capable of treating the volatile organic compounds detected at the General Switch site. The remedial alternatives for groundwater recovery and treatment are discussed in Section 9.0 of this Report.

8.10.3 Free Product (DNAPL) Recovery System

Free product tetrachloroethylene, which is heavier than water (DNAPL), was detected in the bottom of well W-30. Upon detection, a free-product recovery system was installed, with approval from the USEPA, in the base of the well to remove DNAPL. Section 3.0 contains a more detailed description of the free product recovery system.

The bottom-loading pump has a sensor to detect free product, which automatically cycles the pump when enough product has accumulated. The product is piped to a storage container located in the shed that houses the compressor and controls for the system. The product storage tank is fitted with a product high-level cut-off that shuts down the system when the tank fills with product.

The product recovery system will remain on-site for continuing use. Additional free product in the aquifer near well W-30 (Parella well), if present, will be drawn into the well during groundwater recovery. After prolonged groundwater recovery, the free product should be completely remediated, at this time the free product pump will be removed from the well.

8.10.4 Groundwater Recovery System

Section VII(A) of the Consent Decree states that the primary objective of the long term pump test on well W-30 is as follows:

> "The pump test shall be performed for the purpose of demonstrating that the Parella well is satisfactory for interception (through pumping/capture) of the contaminant plume underlying or near the site."

The interpretation of the hydrogeologic data obtained from the various aquifer tests indicates that well W-30 by itself will not be effective in achieving capture of the entire plume. The extent of capture of well W-30 includes a large portion of the plume; however, the contamination that exists considerably sidegradient or downgradient would not be captured.

Based on this observation, a multiple recovery well based system should be employed to capture the full extent of the plume. A multiple well based system would be effective in capturing the plume as long as the capture zones were hydraulically connected or overlapping. The pattern of proposed pumping wells and their potential area of influence is presented in Section 9.0 of this Report.

8.11 RECOMMENDATIONS FOR ADDITIONAL INVESTIGATION

The activities set forth in the RSAMP were completed. However, the groundwater contaminant plume has not been fully delineated in the area south and southeast of the General Switch site. Further groundwater investigation consisting of installation and sampling of a limited number of additional glacial till wells and shallow and deep bedrock wells is required in this area to define the extent of the plume.

The soil borings performed in area TP-A adequately define the extent of contamination outside the General Switch building to the 50 ppm level. The quality of the soil beneath the building has not been characterized to date. Further soil investigation consisting of a limited number of additional soil borings below the building should be performed to provide additional soil quality data.

The scope of these additional activities will be addressed as an addendum to the RSAMP.

SECTION 9

CONTENTS

CONTENTS
(CONTINUED)

9.0 REMEDIAL ALTERNATIVES

This section discusses the feasibility of remedial design options. This section also sets forth the justification for the choice of the proposed remedial method in summary form. Detailed specifications on remedial methods will be developed upon governmental approval.

9.1 REMEDIAL ALTERNATIVES for DNAPL RECOVERY

Free product DNAPL in the glacial till and in the shale should be removed first to prevent any additional contamination. Thus, it is imperative to recover as much as the free product DNAPL as possible. DNAPL recovery systems consisting of extraction wells systems may remove the mobile DNAPL by extracting total fluids (DNAPL and water) or DNAPL only. The wells are usually installed in stratigraphic traps to optimize recovery where DNAPL pools are present. However, a significant quantity of DNAPL will remain trapped within pore spaces subsequent to the removal of mobile DNAPL.

9.1.1 Containment versus Restoration

Except for excavation, there are no proven technologies to reduce the total mass of subsurface DNAPL to levels low enough to effect full restoration of a contaminated aquifer. The hydraulic containment of dissolved-phase contamination is fairly well understood and technically feasible.

Although it is feasible to envision containment of a nonaqueous (DNAPL) phase by physical or hydraulic barriers such as cut-off walls, drains, wells, and artificial hydraulic gradient, these methods are not appropriate for the General Switch site because of the geology of the area.

9.1.2 Enhanced DNAPL Recovery Methods

Recovery of DNAPL from the soil may be enhanced by injecting fluids or agents in the DNAPL zone to increase hydraulic gradients, reduce water/DNAPL interfacial tension, reduce DNAPL viscosity, and/or increase DNAPL solubility flushing the hydrocarbons to recovery wells. However, there are practical technical problems which limit the effectiveness of these methods in the field. The complex subsurface distribution of DNAPL is a function of geologic heterogeneities. Most of the techniques were developed for enhanced oil recovery (EOR) applications. Consequently, very little information is available concerning field applications of enhanced DNAPL recovery techniques at spill sites. Due to the limitations discussed above, these methods are not recommended.

9.1.2.1 Induced Gradient/Water Flooding

Where DNAPL is pooled on lower permeability layers, inducing DNAPL to flow to wells may be an effective means of achieving significant mass removal. The feasibility of removing DNAPL through induced flow is influenced by site-specific characteristics such as pool thickness, DNAPL viscosity, hydraulic conductivity, relative permeabilities, and capillary pressure. If soil flushing is employed, total containment of the mobilized DNAPL must be guaranteed by rigorous hydraulic control of the result of groundwater flow by surrounding recovery wells. Due to this limitation this option is not recommended.

9.1.2.2 Chemically Enhanced Recovery

Surfactants, cosolvents, and alkaline agents are primarily used to increase the solubility of DNAPL constituents in groundwater. These methods have been developed by the oil industry to recover DNAPL crude oil fuels.

However, in addition to increasing DNAPL solubility, surfactants enhance DNAPL mobility by lowering the interfacial tension between the nonaqueous phase and water. The reduction of interfacial tension can produce uncontrolled vertical and lateral migration of previously immobile DNAPL trapped as isolated, lenses or pools accumulated on lower permeability strata in the aquifer. The mobilization of such DNAPLs could greatly exacerbate groundwater problems at this site without rigorous hydraulic control; thus, this option is not recommended.

9.1.2.3 Thermally Enhanced Recovery

Thermal methods of soil flushing involve injecting hot water or steam in an effort to mobilize the DNAPL. The elevated temperature increases volatilization and solubilization and decreases viscosity and density. The mobile phases of the DNAPL are then recovered using a secondary approach, such as pumping or vacuum extraction. This approach (Contained Recovery of Oily Wastes) to enhance recovery of DNAPL is currently under EPA's Superfund Innovative Technology Evaluation Program and a pilot-scale demonstration is forthcoming (21). There are high energy costs associated with inducing the elevated water temperature with significant heat loss in the formation (36).

9.1.3 Proposed Method for DNAPL Free-Product Recovery

In arriving at the proposed remedial method the preceding alternatives were considered and dismissed as impractical or ineffective based upon the General Switch site characteristics.

General Switch proposes to continue DNAPL recovery of the solvent in W-30 by pumping W-30 for a period of time prior to initiating the groundwater pump and treat program from additional wells so that the DNAPL is not pulled in opposite directions. This period of time would be the time during which free product continued to be recovered efficiently. The free product detected in the bottom of the W-30 will continue to be removed from the bedrock aquifer by the free-product recovery system already operating (Figure 2-23).

The system has removed approximately 10 gallons of DNAPL and emulsions to date.

9.1.3.1 Drawdown Pump System

The pump test of the W-30 well (Parella) indicated that significant amounts of solvent dissolved in the groundwater may also be removed from the well. In order to increase the efficiency of capture of the DNAPL, a dual pumping system will be installed in W-30. In addition to the present solvent pump, a water-table depression pump system will be installed in the well. The drawdown pump will draw in the contaminated groundwater to depress the water table to facilitate the recovery of free product. The drawdown cone developed will provide the hydraulic control required to enhance capture the DNAPL.

The drawdown pump will be positioned above the bottom of the well to remove the dissolved phase contamination. Since free product will be removed by the product recovery system, the groundwater pumped from the water-table depression pump will not contain any free product.

9.1.3.2 Advantages

This dual pumping system has the decided advantage in that it will enable the separate recovery of groundwater and DNAPL from the well.

9.1.3.3 Monitoring

The recovery of product from the well will continue to be monitored more frequently if necessary. The product recovery, groundwater pumpage, and static water levels will be recorded monthly.

9.2 REMEDIAL ALTERNATIVES FOR SOIL TREATMENT

9.2.1 Pathways of Dispersion at the Site

The major pathways of dispersion of volatile contaminants at this site are by production of leachate that infiltrates into the groundwater and by air dispersion of volatiles when contaminated soil is disturbed. At present the infiltration of volatile contaminants in the soil into the groundwater is considered to be one of the potential impacts of the contaminants at General Switch. At present the soil at TP-A is surcharged with groundwater contaminated with 1,500 ppm tetrachloroethylene formed from infiltration of water from the surface. A seasonal perched water condition is observed and the resultant leachate production is infiltrating into the groundwater beneath the site. There are no methods or series of methods which have been demonstrated to completely remove contamination from the soil except by complete excavation. Vapor extraction may be used to remove the residual soil contamination and contamination, if present, under the building where soil excavation is not feasible. Based on previous experience with contaminated soil and groundwater, these two technologies were identified for minimizing the impact of on-site soil contamination.

9.2.2 PROPOSED METHOD: SOIL EXCAVATION AND IN-SITU TREATMENT

Two alternatives will be investigated during the remedial design phase for soils with tetrachloroethylene contamination above 50 ppm: excavation and removal from the site, and excavation and on-site treatment. Cost estimates for soil removal are currently being obtained to compare the costs of removal versus on-site treatment. The more cost-effective alternative will be implemented, subject to the ability of that alternative to meet all regulatory requirements.

The use of soil excavation and vapor extraction will minimize leachate production and infiltration into the groundwater. Once the soil contamination is removed, further leachate production and the impact of downward percolation of leachate into the contaminated aquifer from this soil will be eliminated.

9.2.2.1 Soil Excavation

General Switch proposes to excavate and treat the significantly contaminated soil at these two hot spots detailed in the plan view and cross-section (Figures 5-6 through 5-15).

The excavation will be conducted under negative pressure in a plastic tent. The ambient air in the tent and downwind air quality during excavation will be monitored.

TP-A: Area TP-A is by the back door at the rear of the General Switch building in a natural depression adjacent to the building footings, sandwiched between the building and the adjacent property fence. The excavation at TP-A will extend to the bedrock at 12-14 feet deep. Based upon the soil boring analyses and subject to slope stability, the excavation will extend 5 feet from each wall of the building and 5 feet from the property line, be approximately 60 feet long and will encompass all soil with contamination above 50 ppm tetrachloroethylene in an area surrounding soil boring locations T-20, T-17, T-16 and T-15 from the Fred C. Hart Study and OB-9, VES-1 and SB-6 soil borings from the RSAMP investigation, provided the building foundations are not undermined.

TP-D: At the hot spot located adjacent to the loading dock, contaminated soils within the area of TP-D will be excavated within the vicinity of SB-12. The soil will be tested with the Photovac for the volatile content soils. Soil with contamination above 50 ppm tetrachloroethylene will be excavated.

9.2.2.2 Post-Excavation Soil Sampling

A Photovac GC 10S50 will be operating on site during the excavation to guide the operation as to the extent of contamination. Samples of the soil in the base of the excavation will be obtained and analyzed in the laboratory. These confirmatory laboratory samples will be analyzed by USEPA Method SW846 (Method 624 modified for soils analysis). The excavation will be backfilled with clean soil upon confirmation that the post-excavation sample results are within acceptable limits.

9.2.2.3 Vacuum Extraction

Under certain conditions, soil vacuum extraction (SVE) technology has been demonstrated to remove large quantities of volatile DNAPLs from the vadose zone. This technique requires the application of vacuum to the unsaturated zone, thereby inducing air flow and enhancing the removal of many volatile organic contaminants (VOCs). The VOCs are removed from the subsurface by gas transport and treated above ground.

It is easier and less costly to remove a solvent from soil by vapor extraction than to remove the same amount of contaminant from the groundwater by air stripping as there is additional energy expended by the air stripper in moving the volatile across the phase change from solution into the vapor phase.

Thus, it is important to remove residual contaminants that can be mobilized by vapor extraction above the water table rather than flush them, or allow precipitation to wash them into the aquifer below.

Soil vacuum extraction (SVE) is a remediation technology which involves applying a vacuum to unsaturated subsurface strata to induce air flow. Figure 9-1 illustrates that the volatile contaminants present in the contaminated strata will evaporate and the vapors are recovered at the surface and treated. Common methods of treatment include granular activated carbon, catalytic oxidation, and direct combustion. SVE can effectively remove DNAPL present as residual saturation or its soluble phase components in the unsaturated zone. The same strategy is applicable in the saturated zone where DNAPL removal by SVE is attempted concomitantly with lowering the water table. Upon lowering the water table, SVE can be used to remove the remnant volatile wastes not previously recovered.

9.2.2.4 Dewatering and Vapor Extraction of the Excavation

The remedy of in-situ vapor extraction will address the remaining soils if any are above 50 ppm tetrachloroethylene adjacent to the foundation (Figure 9-2). If soil is encountered in the bottom of the excavation at a concentration more than 50 ppm that cannot be excavated without undermining the foundation, piping will be installed in the bottom of the excavation above bedrock and used in vacuum extraction. The piping will be arranged down the center of the excavation and stretching across the limits of the excavation parallel to the north wall of the building. The piping will be set on a bed of crushed stone and additional crushed stone will be poured over the piping. The vapors from the soil above 50 ppm around the foundation will be drawn into the vapor extraction system.

The gravel bed will be covered with 8 mil plastic sheeting to keep out soil fines and provide an impermeable vapor barrier to seal the excavation. The excavation will be capped with a liner and low permeability soil to seal the excavation. The cap will prevent surface short-circuiting of the air flow from the surface. There will be no surface water infiltration into the hot-spots.

The water table is approximately four feet from the ground surface at TP-A. The excavation will be backfilled with porous fill on top of the bedrock that will contain a sealed dewatering sump (Appendix 9). The dewatering piping, located 2 feet below the vapor extraction piping in the bottom of the excavation, will lower the water table and increase the depth of the vadose zone so that the vapor extraction system may reach out under the foundations. The drawdown water will be pumped to the air stripper.

9.2.2.5 Treatment of the Soil Piles by Vapor Extraction

General Switch will excavate and stockpile the soil into two, lined cells containing soil contaminated above 500 ppm tetrachloroethylene and soil contaminated above 50 ppm. A front-end loader will stockpile the segregated soil in two cells.

Soil treatment will be applied to reduce the volatile concentration of tetrachloroethylene by 95-99.9% in accordance with the guidance "Interim Treatment Levels for Soil and Debris, June 1, 1988, USEPA Office of Emergency and Remedial Response. Applying the guidance, we are proposing the treatment levels in Table 1A for Organics. The table data on contaminants are divided into chemical groups. Tetrachloroethylene is a halogenated aliphatic compound. Each chemical group has two types of treatment levels. The first is a concentration range for lower levels of contamination; these concentration ranges are similar to residual concentrations being proposed by OSW in setting BDAT standards for RCRA-listed waste codes. The second is a percent reduction range for higher concentrations of contamination. When the indicated threshold concentration is exceeded for a particular constituent in the untreated soil or debris, then the treatment level for that constituent is to achieve a reduction of the contamination in the untreated waste within the range of the corresponding percent reduction.

Table 1A 5/27/88

Treatment Levels for Treatability Variances
for Contaminated Soil and Debris*
Organics
(concentration based on total waste analysis)

Structural Functional Group	Treatment Range (ppm)	Threshold Concen. (ppm)	Percent Reduction Range
W01 - Halogenated Non-Polar Aromatics	0.5-10	100	90-99.9

For example, according to the guidance, a soil with 200 ppm of tetrachloroethylene, a halogenated aromatic compound, would have a goal of 10 ppm to achieve 95% reduction for a maximum residual level after treatment. For untreated wastes which significantly exceed the threshold concentration, the percent reduction must approach the upper end of the range.

As the concentration of tetrachloroethylene increases significantly above the 200 ppm level, the reduction must approach 99.9% reduction to approach the residual goal of 10 to 50 ppm. Soils above 50 ppm that do not reach the 99.9% reduction after treatment are scheduled to be removed from site for incineration or disposal in a secure landfill, depending upon the waste classification.

When the untreated concentration is between the treatment level and the threshold concentration 0.5 to 100 ppm, the treatment should reduce the concentration in the residuals to no more than the maximum of the treatment range (in this case, the percent reduction does not apply). When the untreated concentration is above the threshold concentration of 100 ppm, the treatment should achieve at least the minimum of the percent reduction range of 10 ppm.

9.2.2.6 Monitoring

The soils contaminant levels will be confirmed with laboratory analysis upon completion of soil treatment. Based on the analytical results for each portion of soil pile, a decision will be made as to whether to reduce the contaminant levels further or dispose of the soil off site in a secure landfilling.

9.2.2.7 Advantages

The site will be closed in a manner that reduces the concentration of contaminants to an acceptable level in the upper soil horizons, reduces post-closure release of leachate, contaminated run-off and waste decomposition products to groundwaters of the state or to the atmosphere and minimizes or eliminates exposure to human health and the environment.

9.2.2.8 Disadvantages

Soil excavation will be effected inside an enclosure under negative pressure and vented through carbon. Air monitoring will be conducted with a microtip PID to determine the fence line exposure. If contaminant levels reach 5 ppm above background, 5 feet from the exterior perimeter of the tent, excavation will be stopped.

The majority of the work will be mechanized. Level B protective equipment including air supplied respirators from cascade systems will be used by remedial workers during soil excavation and placement in the soil cells. The site TP-D in the parking area is remote from residential dwellings. Access to the sites will be restricted during soil excavation.

9.3 REMEDIAL ALTERNATIVES FOR GROUNDWATER RECOVERY

9.3.1 Pump and Treat

Pump-and-treat will be used to remediate the dissolved-phase contamination.

Traditional pump-and-treat systems, which recover and treat aqueous contamination, are useful components in many remediation programs. These systems are used to prevent plume migration and reduce contaminant concentrations in areas contaminated solely with aqueous and sorbed constituents.

Selected deep bedrock wells will be used to recover contaminated groundwater from the fractured bedrock at the site.

Trench systems will be used to recover dissolved contaminants in the areas where the formation will yield little water to wells. Recovery lines are placed horizontally on top of the impermeable stratigraphic unit. DNAPL and contaminated groundwater flows into the collection trenches and seep into the recovery lines. The lines usually drain to a collection sump where product and groundwater is pumped to the surface.

9.3.2 Proposed Method: Interceptor Wells/Trench for Groundwater Capture

9.3.2.1 The Issue

A plume of tetrachloroethylene contaminated groundwater has been demonstrated in the fractured bedrock aquifer in the vicinity of the monitor wells MW-202, MW-203 and MW-207 and residential wells: W-30 (Parella), W-32 (Stout), W-33 (Contel), W-18 (Ruppert) and W-17 (Barry) and in the glacial till at hot-spots TP-A and TP-D and at MW-3 and MW-4, MW-5 and MW-9 in the wetlands.

9.3.2.2 Description of Alternative

Based on available data, the well W-30 pumping at its maximum long-term yield of 2 gpm has an sufficient radius of influence an ellipse with downgradient 85 feet, upgradient 534 feet and side-gradient 26 feet (Section 4.3.4.7) along the fractures in the shale. It controls the hydrology of the worst contaminated area. Pumping well W-30 will pull down the potentiometric head in the well approximately 100 feet. The well is situated close to a major fracture in the area and will intercept the flow of groundwater contaminants flowing past the well to Highland Avenue. Well W-30 (Parella) will be pumped with a dual-pump system. The drawdown pump, located 20 feet from the bottom of W-30, will be pumped to draw contaminated groundwater into the well and draw down the water level.

The pumping rates will be regulated by high and low level probes such that well W-30 will be pumped at its maximum capacity until free product is no longer being recovered efficiently. The remaining groundwater recovery wells will then be pumped.

Groundwater from the proposed recovery wells in the bedrock, that include the W-17 (Barry), W-33 (Contel), W-32 (Stout), and W-30 (Parella) residential wells and MW-202, MW-203 and MW-207, will be pumped to produce the zone of capture needed to influence the entire plume.

A pump test of well W-30 and step tests of the other proposed pumping wells have been conducted to demonstrate the specific yield and zone of influence of the proposed pumping wells and to define the effect of pumping for an extended period of time on the hydrology of the site in order to provide reliable drawdown predictions.

The proposed recovery wells are already drilled, but will need to be connected to the air stripper through piping set in trenches below the frost line. A pump and associated water level sensing probes will be installed in each well connected to an electronic control box at the air stripper to regulate the pumping rates based on the drawdown at each well. The interceptor trench is not yet installed. A pilot trench will be installed between MW-5 and MW-4 and the rate of groundwater withdrawal will be used to determine the yield of the interceptor trench and the need for additional trenching.

To address the solvent plume in the glacial till at TP-A, a sump installed at VES-1 will be pumped to treatment. The plume of dissolved solvent below the water table in the wetlands will be removed from the groundwater in the glacial till by using an interceptor trench adjacent to MW-3 and MW-4, MW-5 and MW-9 in the wetlands. The trench design was chosen instead of pumping the monitor wells based on the greater efficiency of a trench and sump system in collecting groundwater in a tight glacial till.

9.3.2.3 Advantages

The recovery system will intercept contaminants flowing southward along Highland Avenue and through the wetlands.

The plume will be captured by physically altering the potentiometric pressure in the aquifer, altering the regional direction of groundwater flow and providing a drawdown cone under the site. Within the zone of influence of the pumping well, the contaminated groundwater will flow to the recovery wells where it will be permanently removed from the aquifer.

9.3.2.4 Disadvantages

The water resources of the area around General Switch will be reduced during the time of groundwater treatment. However, the effect on regional water resources is expected to be minimal. Up to 1984, over 30 wells in the vicinity of Highland Avenue were drawing water from the aquifer and the regional water table was pulled down approximately twenty feet. These households now have a municipal water supply. Thus, the demand for groundwater is eliminated, and pumping the recovery system will not affect the use of available water supply.

9.4 GROUNDWATER TREATMENT

The Consent Order stipulates the following requirements with regard to aquifer restoration:

- Aquifer restoration to 5 ppb of tetrachloroethylene (PCE).
- Cleanup of groundwater by air stripper at 99.9% or greater efficiency so that the effluent contains less than 5 ppb of tetrachloroethylene, 5 ppb trichloroethylene, 5 ppb of dichloroethylene and 2 ppb of vinyl chloride.

9.4.1 Proposed Method: Air Stripper

The groundwater from the recovery wells will be pumped through an air stripper that will reduce the anticipated groundwater contaminant concentration influent to the system to 5 ppb in the effluent. As the air stripper design has proven reliable, an activated carbon backup filter is not required however a carbon filter will be used to polish the effluent discharge.

9.4.2 Data Needs

The data required to design, size and permit the air stripper has been obtained by operating the pilot plant during the RSAMP. The step tests of the bedrock wells and the slug tests of the monitoring wells indicate that a 60 gpm capacity air stripper is appropriate. Based on the step tests, the proposed recovery wells will yield the following flow rates: W-30 (Parella, 2 gpm), w-32 (Stout, 4 gpm), W-33 (Contel, 6 gpm), W-17 (Barry, 2 gpm), MW-202 (0.25 gpm), MW-203 (4 gpm), MW-207 (15 gpm) and VES-1 (1 gpm). The interceptor trench is expected to yield 15 gpm, however the actual yield of the trench will be measured during the proposed pilot test of the trench.

9.4.3 Feasibility

The system has been operated during the RSAMP with success to treat the variety of concentrations of leachate from the proposed recovery wells. The background information on air stripping is contained in Section 6.0.

The air exhaust will be filtered through two carbon filters arranged in series. Periodic air monitoring between the carbon filters will indicate when breakthrough has occurred it will prompt replacement of the upstream filter.

9.4.4 Advantages

The air stripper has already been proven to be effective on the General Switch site and operates for long periods of time.

Sufficient information has been to evaluate the field performance of the air stripping technology. It is a high efficiency, low-cost technique for purging volatile organic chemicals from water. It is effective, practical, operable, flexible, reliable, and amenable to fabrication in the field at a scale tailored to the problem of the site. It can be fabricated of materials capable of withstanding high or low Ph liquids. It has no moving parts in contact with the liquid being stripped and so is relatively free from the effects of abrasive materials.

9.4.5 Secondary Environmental Impact

Air stripping can cause a potential air pollution problem if the exhaust is emitted directly into the air. A vapor phase carbon filter will be provided to purify the exhaust and avoid any air pollution impact.

9.4.6 Permits

Review by state regulatory authorities will be required for all media permits, if applicable.

9.5 SAMPLING AND ANALYSIS

The reliability of the Photovac 10S50 has been demonstrated on site by producing consistent and dependable results during implementation of the RSAMP on which to base decisions in the operation of the air stripper. The Photovac has consistently detected tetrachloroethylene in groundwater samples in the low parts per billion range. The range of concentrations treated by the air stripper varied from 670 ppb to 150,000 ppb. Once the treatment system is hooked up to specific wells, the influent concentration to the air stripper will be consistent and will allow less monitoring of the effluent.

The Photovac has consistently detected breakthrough of exhaust gases through the first carbon system in producing results that are between 10 to 100 times more sensitive than the laboratory results. During the site investigation, tetrachloroethylene was found to be the most significant volatile organic and may serve as an indication parameter during site cleanup. Thus, Method 601 may be used henceforth. All soil and water samples will be analyzed using a Photovac Portable Gas Chromatograph. In addition, one of every 10 water samples will be analyzed for tetrachloroethylene (Method 601) in an independent, mutually acceptable laboratory during the first week of operation and then one in every 20 samples thereafter.

9.5.1 Startup

Flows, pressures and vacuum controls will be set and monitored each month. An automatic shutoff will be installed to prevent overflow in the event of transfer pump failure. The system will be fitted with an auto-alarm dialer that will call in an alarm in case of pump malfunction, blower failure or system shut down.

For the first week of operation, the system will be checked twice a week. For the first month, it will be monitored weekly, and thereafter monthly.

9.5.2 Groundwater Sampling

During the operation of the air stripper, General Switch will sample the groundwater from the following wells every six months to indicate the progress of the groundwater cleanup: W-18 (Ruppert), W-17 (Barry), W-33 (Contel), W-32 (Stout), W-31 (Electra), MW-202, MW-207, MW-203, MW-3, MW-4, MW-5 and MW-9. The sampling protocol set forth in the RSAMP will be followed.

9.5.3 Quality Control of the Treatment Process

Samples will be taken periodically according to the approved sampling plan and analyzed by a CLP laboratory. One influent and effluent Photovac water sample and one Photovac air sample between the vapor phase carbon filters will be obtained on the first day of operation, after the first week and subsequently every month of operation.

For quality control of the treatment process, the following samples will be required according to the Sampling and QA/QC Plan.

- Each month: Photovac samples of treatment system influent and effluent.
- Each month: One Photovac air sample between the carbon filters on the exhaust.
- Each quarter: Quality Control (QC), Trip and Field Blank.
- Each quarter: Laboratory sample of treatment system influent and effluent.

9.6 COMPLETION OF CLEANUP

9.6.1 Groundwater Cleanup

The completion of the groundwater cleanup will be achieved when the groundwater that is recovered during the pumping from the recovery wells yields readings below the adopted criteria of 5 ppb of tetrachloroethylene. The groundwater cleanup system will be shut down at that time. After the influent concentration reaches 5 ppb, in order to confirm that the cleanup standard is maintained, General Switch will then proceed to monitor and analyze one influent sample from the interceptor well on a quarterly basis. These samples will be analyzed by a USEPA-approved laboratory. If the analytical results show tetrachloroethylene levels of less than 5 ppb, the cleanup will be deemed complete (i.e., the achievement of the stated criteria). If the groundwater tested at that time exceeds the stated criteria, then treatment will be resumed.

9.6.2 Soil Cleanup

The completion of soil cleanup will be when the agreed upon volume of soil is excavated and treated, thereby reducing the soil solvent concentration by the 95% - 99.9% criteria set forth in the Consent Order. The site will be given a release from the Consent Order at the end of groundwater cleanup and soil treatment after the groundwater has maintained a concentration at or below 5 ppb.

9.6.3 Dismantling of Equipment

At the completion of the cleanup, the air stripper will be disconnected from the piping from the recovery wells. The vapor recovery equipment will be disconnected. The soil pile consisting of treated soil entombed in 8 mil plastic will be covered with 6 inches of topsoil, seeded and remain in place.

The piping from the recovery wells will be disconnected and the recovery wells will be sealed with padlocked caps. The excavations will be backfilled with clean fill.