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THE MIGRATION OF HYDROCARBON CONSTITUENTS FROM A CONTAINMENT TANK

by

VIRGILIO A. MINIÑO

A dissertation submitted to the Graduate Faculty in Earth and Environmental Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

2000

This manuscript has been read and accepted for the Graduate Faculty in Earth and Environmental Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

09-19-00
Date

Chair of Examining Committee

09/19/00
Date

Executive Officer

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Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract

THE MIGRATION OF HYDROCARBON CONSTITUENTS

FROM A CONTAINMENT TANK

by

Virgilio A. Miniño

Advisor: Professor Arthur M. Langer

On February 27, 1996 a single bare steel 4,000 gallon gasoline underground storage tank (UST) was removed from the New Jersey Department of Transportation (NJDOT) Maintenance Facility at Hackettstown, Morris County, New Jersey. This UST was used for the storage of unleaded gasoline. Since there is no record on the date of the installation of this tank, and based eyewitness account, there is a suspicion that this tank also stored leaded gasoline. This tank did not have cathodic protection nor any other protection for spills and overfills. At the time of the removal of the tank, holes were observed in its walls. Following New Jersey Department of Environmental Protection (NJDEP) directives a series of monitoring wells were installed to accurately determine the extent of contamination. The creosote used on light poles was also taken into account as a source of potential hydrocarbon source.

Monitoring wells in the immediate area of the former UST had considerable amounts of pure product (gasoline and petroleum components). Further studies

determined that the extent of the free fuel plume may have reached 1,400 feet downgradient west from the source. However, there was a significant discrepancy between the data provided by the model and the data collected from monitoring wells. Contaminants were found only at approximately 800 feet from the source. The contaminants studied were benzene, chloromethane, toluene and methyl tertiary butyl ether (MTBE). A tri-dimensional computer model was used for these studies (MODFLOW). This program takes into account such factors as the permeability, gradient, total porosity, effective porosity, fractures and all the characteristics of the soil, dispersivity, half-life of the contaminants, decay and retardation parameters of the contaminants, velocity and dispersion of the groundwater, precipitation, seepage and surface runoff. In addition, capillary action and biodegradation were also taken into account.

The site is located within two geological physiographic units: the Piedmont and the Highlands. The UST was located in a recharge zone approximately at 710 feet above mean sea level. The movement of groundwater in the vicinity of the UST is more vertically/downward than lateral. The soil is a mixture of weathered gneiss and glacial till. Bedrock was found in the range of 6.5 to 35 feet below the surface. The bedrock showed fractures spacing from approximately 0.25 to 6 inches.

Groundwater was sampled according to the New Jersey Department of Environmental Protection (NJDEP) directives. The samples were analyzed using trap

Gass Chromatography/Mass Spectrometry (GC/MS).

MTBE is the only contaminant presented in this thesis that has been detected downgradient of the groundwater treatment system. However, its low concentration (a maximum of 0.67 ppm is indicative of no health hazard at the study site).

Acknowledgments

I wish to thank Professor Arthur M. Langer, who devoted so much of his time to guide me through this thesis. Not only he supported me all through the difficult times for the past few years, but was always encouraging me during those times. I also would like to thank Professor David Locke and Professor Frederick Shaw, members of my dissertation committee, for their valuable suggestions. Professor Jeffrey P. Osleeb, Executive Officer of the Earth and Environmental Sciences Department, was very supportive, so I would like to thank him too. This thesis was made possible by the New Jersey Department of Transportation, who permitted me to use the data, and by Dresdner Robin Environmental (DREM), who provided me with such data. Without their cooperation this dissertation would have not been possible. I would like to thank Mrs. Lina McClain, the Earth and Environmental Sciences Department Program Coordinator. Mrs. McClain sometimes is taken for granted by some students, but she was also very helpful in coordinating all the appointments regarding my studies in the program. I also would like to thank all those students in the program who at some instances encouraged me to continue and finish my Ph.D.

Dedication

I would like to dedicate this thesis to my wife Elsa Yajaira, and to my children Christopher and Amaury Virgilio. They inspired me to finish my Ph.D., and were always supportive. They had to sacrifice themselves many times so I could work on my research. I also would like to dedicate this thesis to my parents Dolores and Ramon, as well as my brothers and sisters Winston, Altagracia, Marina, Vicente, Rosa, Xiomara, Gloria, Gladys, Margarita, Marino, Ramon, Dalma, Yocasta and Joaquin. They also were very supportive and encouraged me through the difficult times.

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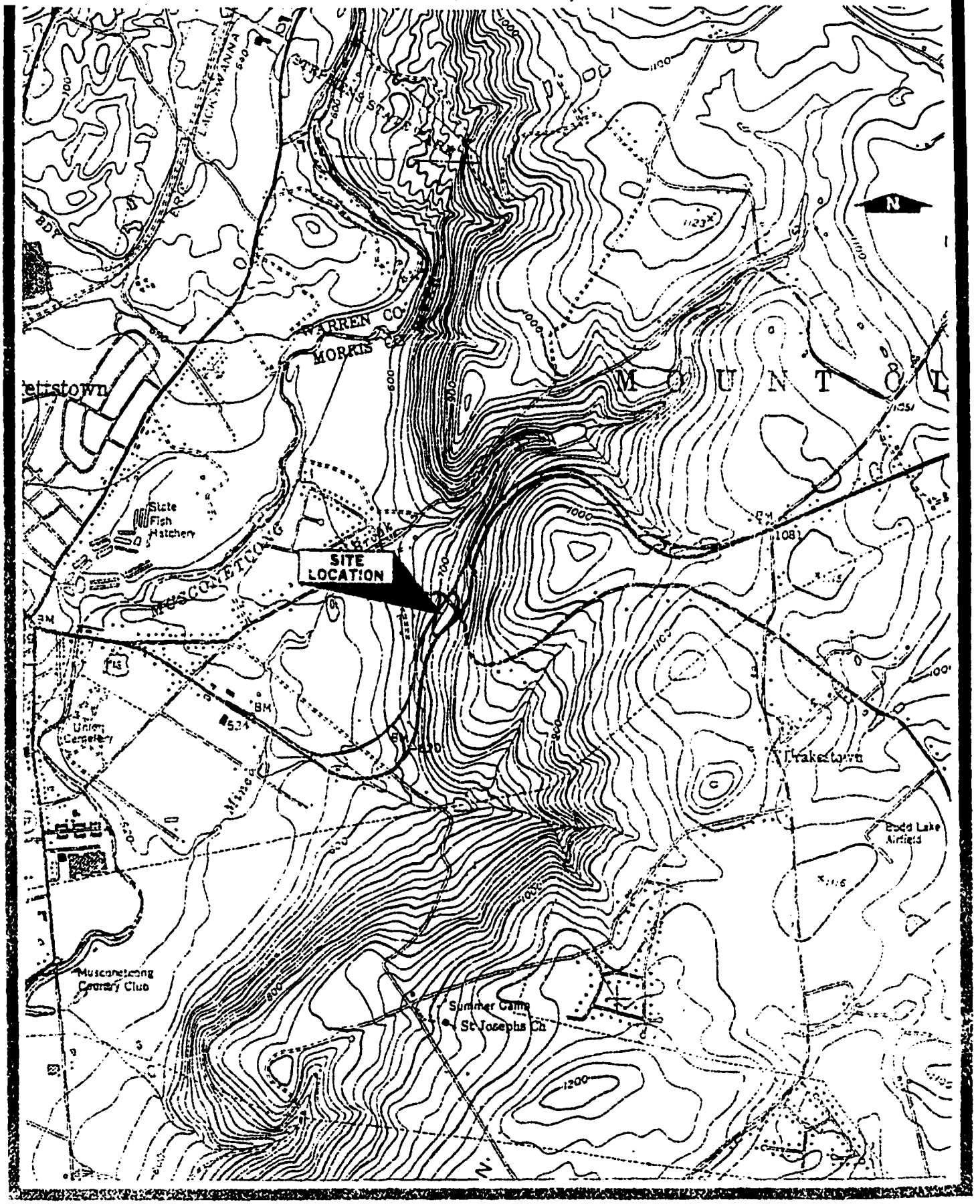
Nature of the Problem

This investigation focuses on a specific and defined underground gasoline storage tank at the New Jersey Department of Transportation (NJDOT) maintenance facility in Hackettstown, Washington Township, New Jersey. Figure 1 is a topographic map showing the location of the study site. The containment breached and over a period of time leaked its contents into the local environment. This thesis describes the geologic control of the leaked effluent in terms of movement and its ultimate fate. This thesis also takes into consideration other sources of contamination, such as surface runoff from a nearby highway, west bound Route 46, the employee's parking lot at the facility, and the on-site truck maintenance garage. The use of creosote on light poles near the site will also be considered as a potential hydrocarbon source.

The author participated in a remedial investigation undertaken by Dresdner Robin Environmental Management (DREM), and the unpublished data are presented here for the first time. Further, the author has integrated the data with the geological and hydrological information available and draws conclusions on how these physical parameters control the nature and extent of the pollution plume. These data may be used to construct inferences in other Underground Storage Tanks (USTs).

Contamination of groundwater by gasoline and other petroleum-derived hydrocarbons, released from USTs, is perceived to be a serious and widespread problem



USGS 7.5 MINUTE SERIES
TOPOGRAPHIC MAP
HACKETTSTOWN, NJ QUADRANGLE
LAT: 40°-50'-57"
LONG: 74°-48'-06"

Location Map

in the United States (US EPA, 1980). Tank corrosion, ground movement, and poor sealing of containment devices can result in leaks in tanks and associated piping. As of 1990, there were about two million underground tanks used to store gasoline in the U.S.; an estimated 90,000 confirmed releases were reported between 1989 and 1990 (OUST, 1990). As reported by the EPA, and as of 1998, there were 919,540 active tanks, with 358,269 confirmed releases in the United States. Table 1 shows the USTs statistics throughout the United States as per EPA regions.

Released gasoline and its additives represent toxic forms of contamination, but they are generally limited in terms of the area they affect (Suflita, 1989). "As gasoline migrates from a spill site, it contaminates soil in the vadose zone" (Freeze and Cherry, 1979). Since gasoline's components are largely water-insoluble and less dense than water, non-contained hydrocarbons tend to reside and spread along the top of the water table-aquifer boundary (Suflita, 1989).

Table 1
Underground Storage Tanks
Statistics
1985 Through 1998

EPA Region/ State	Number of Active Tanks	Number of Closed Tanks	Confirmed Releases	Cleanup Initiated	Cleanup Completed	Systems Equipped with LD Requirements	Systems Equipped to Meet Upgrade Requirements
ONE							
CT	16,777	13,701	1,712	1,668	1,058	1,774	7,902
MA	19,290	4,477	5,088	4,366	2,777	5,247	5,247
ME	11,957	8,735	1,711	1,660	1,570	14,160	not available
NH	3,777	8,790	1,795	1,795	825	2,666	2,886
RI	2,422	5,608	1,079	832	619	not available	not available
VT	3,089	4,100	1,536	1,536	755	2,775	2,120
SUBTOTAL	57,312	45,411	12,921	11,857	7,604	26,622	18,155
TWO							
NJ	28,646	36,394	6,768	5,911	3,652	7,691	5,854
NY	39,110	52,996	14,531	14,053	9,344	18,955	8,924
PR	5,798	2,558	603	581	139	3,112	1,769
VI	299	89	25	15	13	119	119
SUBTOTAL	73,853	92,037	21,927	20,560	13,148	29,877	16,666
THREE							
DC	1,017	2,548	883	883	536	629	413
DE	2,117	5,222	2,379	1,986	1,507	2,026	1,300
MD	19,261	19,578	13,522	12,149	5,755	4,298	3,086
PA	37,250	41,325	9,251	8,888	3,803	8,569	9,970
VA	36,777	32,598	7,513	7,372	6,143	8,806	6,682
WV	7,875	15,029	2,170	1,866	1,006	3,404	2,499
SUBTOTAL	104,297	116,300	35,718	33,144	18,750	27,732	23,950
FOUR							
AL	21,938	22,111	8,925	8,620	7,552	11,632	4,179
FL	34,512	79,792	27,877	9,939	3,554	33,892	32,084
GA	33,277	27,865	6,465	6,465	2,522	19,211	12,413
KY	19,238	23,829	8,219	8,156	6,695	13,559	8,472
MS	10,867	18,227	5,040	4,926	4,639	9,480	5,032
NC	36,092	53,387	19,223	17,806	12,575	28,354	18,002
SC	15,397	25,345	6,434	4,546	2,549	13,808	8,629
TN	23,912	28,061	9,817	9,378	8,294	14,403	11,771
SUBTOTAL	195,233	278,617	92,000	69,836	48,380	144,339	100,582

Table 1 (continued)
Underground Storage Tanks
Statistics
1985 Through 1998

EPA Region/ State	Number of Active Tanks	Number of Closed Tanks	Confirmed Releases	Cleanup Initiated	Cleanup Completed	Systems Equipped with LD Requirements	Systems Equipped to Meet Upgrade Requirements
FIVE							
IL	47,882	31,406	15,314	14,897	6,602	894	4,778
IN	19,326	31,304	5,711	3,605	2,611	not available	not available
MI	28,149	50,727	16,069	15,539	7,360	12,703	10,071
MN	14,801	21,131	6,630	6,024	5,031	13,807	6,509
OH	32,367	29,503	17,118	16,844	12,882	216	937
WI	22,485	52,508	15,758	14,116	7,476	16,811	7,703
SUBTOTAL	165,010	216,579	76,600	71,025	41,962	44,431	29,998
SIX							
AR	20,567	6,106	728	649	313	not available	not available
LA	21,574	19,237	2,126	1,225	944	16,460	9,259
NM	4,203	7,376	2,054	1,455	1,158	4,508	2,316
OK	15,858	15,105	3,309	2,725	1,780	not available	not available
TX	74,598	83,809	20,806	13,023	12,504	56,461	55,585
SUBTOTAL	136,800	131,633	29,023	19,077	16,699	77,429	67,160
SEVEN							
IA	10,008	19,699	5,233	4,178	1,318	7,224	7,224
KS	9,498	16,732	3,916	3,487	1,923	8,275	4,702
MO	14,756	26,994	4,717	4,275	3,288	10,363	4,635
NE	8,950	10,646	4,623	2,144	1,892	6,296	3,777
SUBTOTAL	43,212	74,071	18,489	14,084	8,421	32,158	20,338
EIGHT							
CO	12,980	14,825	4,356	3,916	2,849	14,316	8,437
MT	4,905	10,551	3,208	2,549	1,927	3,043	2,408
ND	3,065	5,518	610	311	311	2,472	1,473
SD	4,512	4,279	1,850	1,661	1,158	4,270	1,496
UT	4,832	10,601	3,133	2,854	2,364	4,817	2,601
WY	2,493	6,950	1,816	705	389	not available	not available
SUBTOTAL	32,787	52,724	14,973	11,996	8,998	28,918	16,415

Table 1(continued)
Underground Storage Tanks
Statistics
1985 Through 1998

EPA Region/ State	Number of Active Tanks	Number of Closed Tanks	Confirmed Releases	Cleanup Initiated	Cleanup Completed	Systems Equipped with LD Requirements	Systems Equipped to Meet Upgrade Requirements
NINE							
AZ	9,026	16,867	6,801	3,821	3,000	7,824	3,367
CA	59,537	88,834	32,010	32,010	15,965	39,959	31,029
HI	2,819	3,205	1,172	800	426	1,465	548
NV	4,359	5,387	2,017	1,803	1,689	2,472	1,311
CNMI	76	12	6	4	0	not available	not available
GU	577	226	93	93	93	not available	not available
AS	28	17	1	1	0	not available	not available
SUBTOTAL	76,422	114,548	42,100	38,532	21,173	51,720	36,255
TEN							
AK	2,296	5,007	1,537	1,295	615	1,025	712
ID	4,812	6,651	1,107	1,005	812	2,499	904
OR	9,859	21,147	5,627	4,174	2,802	3,796	3,796
WA	14,264	28,354	5,274	4,526	2,294	11,436	8,555
SUBTOTAL	31,231	61,159	13,545	11,000	6,523	18,756	13,967
INDIAN COUNTRY	3,383	3,262	973	731	407	1,569	537
TOTAL	**919,540**	**1,186,341**	**358,269**	**301,842**	**192,065**	**483,551**	**344,023**

LD = Leak detection

Source: U.S. Environmental Protection Agency (EPA, 1998)

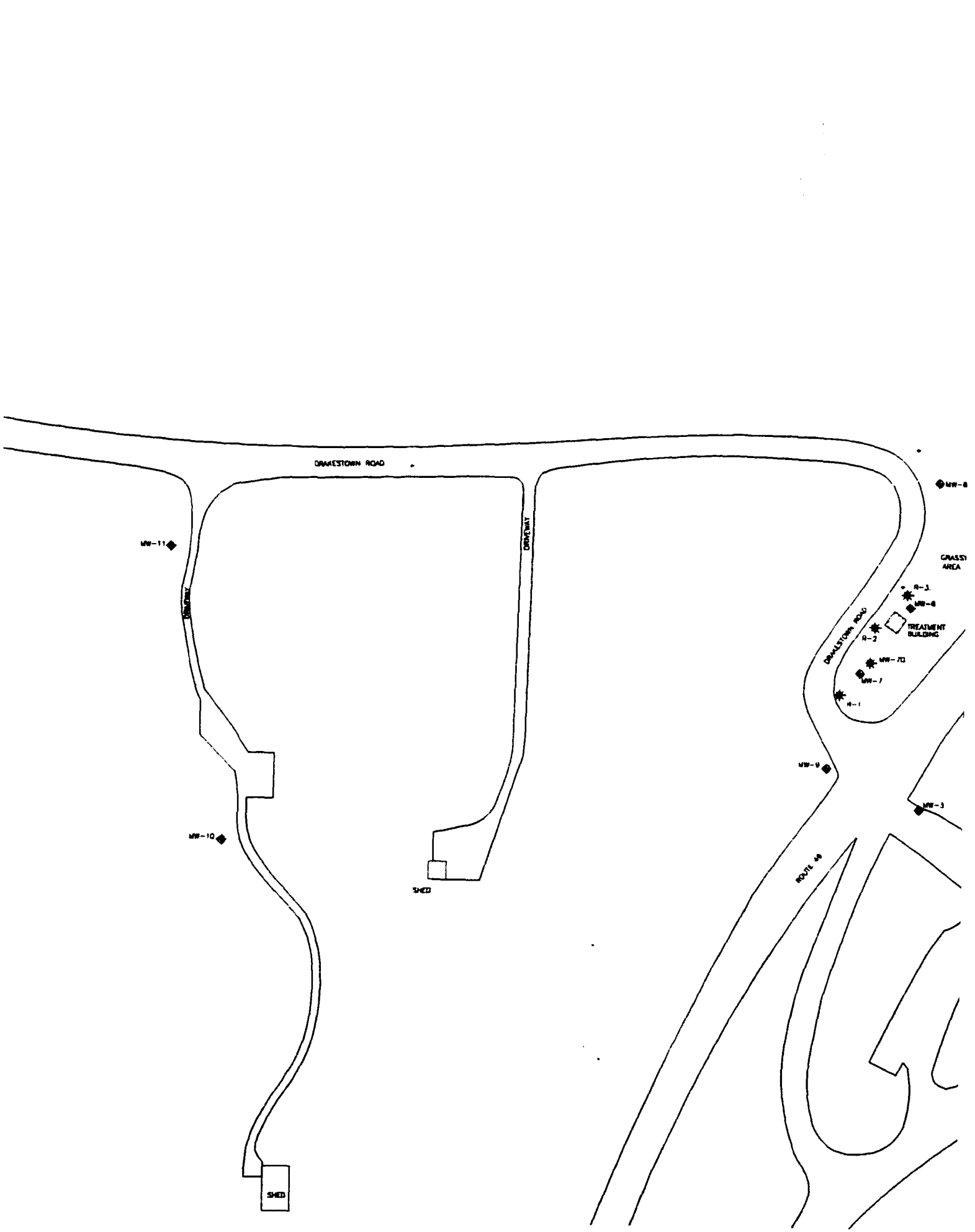
Statistics from 1985 to 1998

Introduction

On February 27, 1996 a single wall bare steel 4,000 gallon gasoline UST was removed from the New Jersey Department of Transportation's (NJDOT) Maintenance Facility at Hackettstown, Morris County, New Jersey. Figure 2 is a map of the study site showing the boring locations. At the time it was removed, the UST was used for unleaded gasoline. However, because of its estimated age and duration of use it was suspected that previously it contained leaded gasoline. Leaded gasoline was phased out starting in 1973 in the United States. The tank was reported to serve a filling station site that was in constant use by the NJDOT. However, no accurate data were available as to how often the tank was refilled so that the service life volume is unknown. The UST had no spill containment around the fill pipe, nor did it have overfill protection, such as a spill catchment basin, bentonite clay, a sensor for measuring the level of gasoline, or a device designed to automatically stop the flow of gasoline into the tank when such tank was 95 percent full.

During the UST removal NJDOT personnel observed holes in the walls of the tank. The excavation at the site measured approximately 12' wide X 30' long X 13' deep. Excavation stopped at approximately 13 feet due to the presence of groundwater. Gasoline was not observed in the groundwater at the time of excavation.

A series of monitoring wells was installed at the site in August 1996. Subsequent



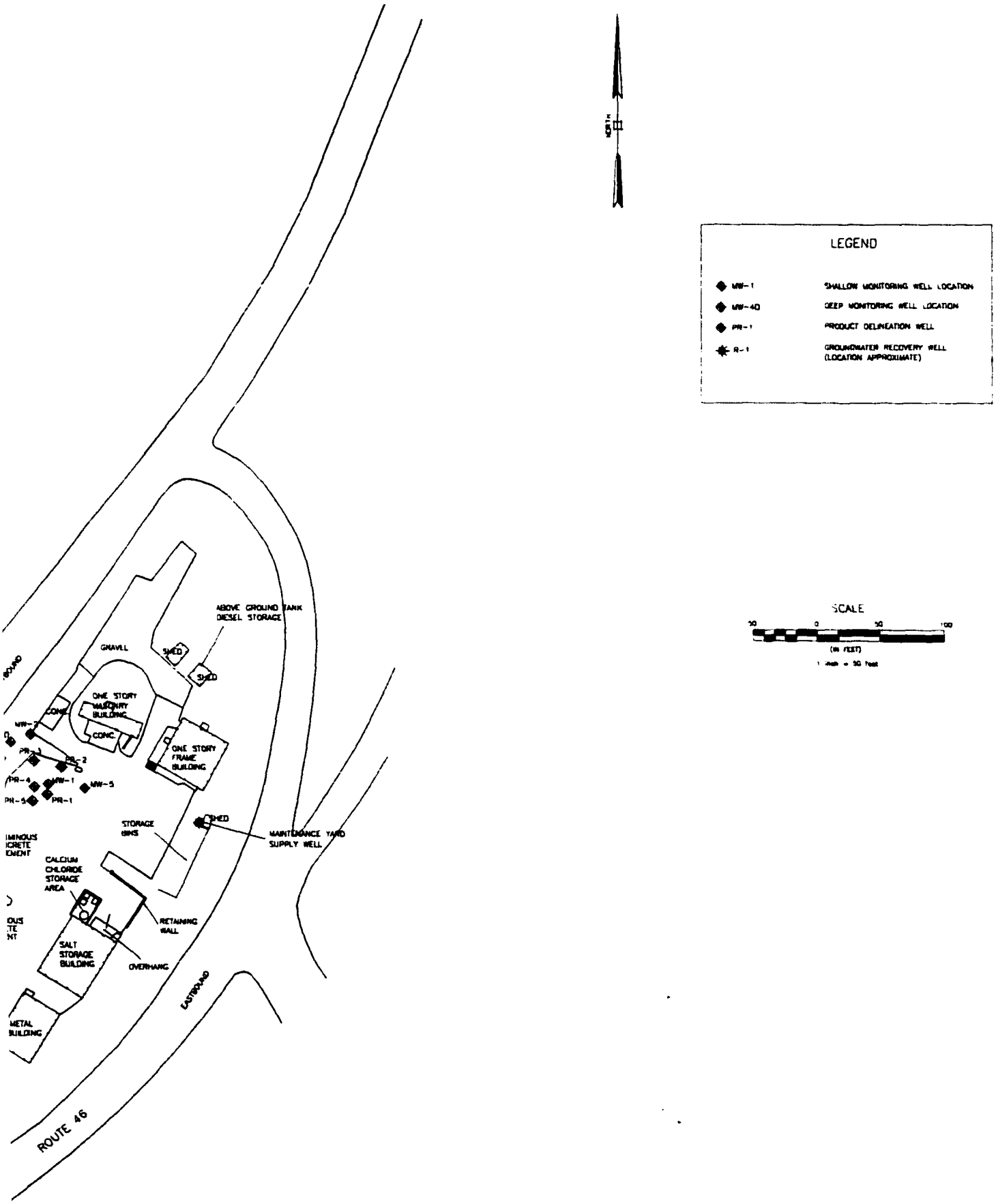
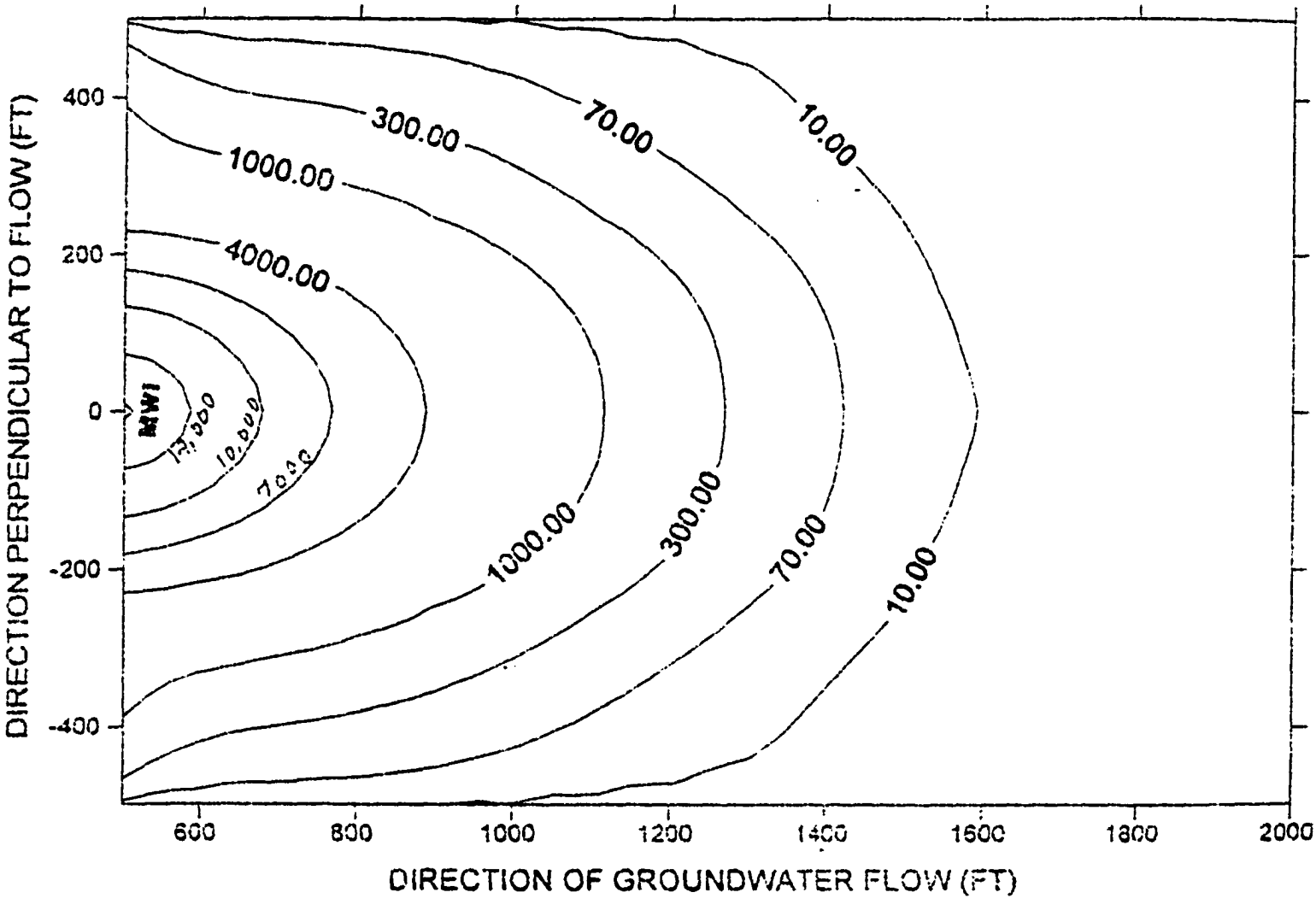


FIGURE 2

remedial investigation included the installation of several other monitoring wells. It was discovered that there was as much as 4 feet of fuel, in depth, measured in the monitoring well in the location of the former UST. Approximately 70 gallons of gasoline were recovered from October 23, 1996 through June 6, 1998 by the use of a pneumatic skimming pump, and also by hand-bailing. The extent of the free fuel and groundwater plume has been modeled and may have reached approximately 1,400 feet downgradient (west) from the source. However, laboratory results of samples taken at the study site show readings below the detection limit at a boring located approximately 800 feet downgradient from the source area. Figure 3 shows contours of Methyl Tertiary Butyl Ether (MTBE) at the study site for August 1997, as predicted by a computer model. More details regarding the computer model are found in appendix 1. Additional modeling is ongoing at the present time in order to measure the extent of the plume more accurately. The plume at the study site was measured by identifying gasoline components after groundwater sampling.

CONTOURS OF MTBE CONCENTRATION (ug/L)
FOR AUGUST 1997 PREDICTED BY PROGRAM HUNT

NJDOT HACKETTSTOWN FACILITY



Geological Setting

Hackettstown, located in Washington Township, Morris County, New Jersey. (Latitude: 40° - 50' - 57", Longitude: 74° - 48' - 06"), lies within two physiographic provinces; the Piedmont and the Highlands (Lucey, 1972). "The Piedmont in New Jersey is a rolling plain underlain by soft shale and sandstone, interrupted to the east by Towakhow Mountain and to the south by Mount Kemble and Long Hill" (Tedrow, 1986). The Highlands consists of a series of flat-topped ridges, separated by narrow deep valleys, and is composed of crystalline, Precambrian igneous and metamorphic members; the valleys are underlain by shale and limestone of Ordovician and Cambrian age (Volkert, 1996). The highest elevation in Morris County is Bowling Green Mountain, which attains an elevation of 1,391 feet above mean sea level (Kilian, 1976).

Topography

The topography of the area surrounding the study site ranges in elevation from approximately 1,000 feet above mean sea level east of the site on Schooleys Mountain, to approximately 300 feet above mean sea level west of the site along the Musconetcong River (USGS, 1976). The mountainside surface slopes to the west toward the Musconetcong River Valley containing Mine Brook, located about 1,800 feet from the site (USGS, 1976). The former UST was located on the slope at approximately 710 feet above mean sea level. The hilly topography produces numerous subsystems within the

major flow system. Water that enters the flow system in a given recharge area may be discharged in the nearest topographic low or it may move on to the regional discharge area in the bottom of the major valley. The simplest indicator of flow direction is the topography. Discharge areas are topographically low and recharge areas are topographically high. Figure 4 is a drawing representing a regional recharge and discharge area. The most direct indicator of flow direction is piezometric measurement. This is shown in figure 5, which is a groundwater contour map of the study site, and which indicates a westerly, downgradient flow direction. Subsequent groundwater contour maps not included in this thesis show a similar groundwater flow direction.

Overview of the Geologic History of the Area

In Morris County, there is evidence that deposition of thousands of feet of sediments took place in a shallow inland sea about 1.3 b.y. (late Proterozoic) (Wilber and Johnson, 1940). These sediments formed conglomerates to clay stone and subsequently were subjected to folding, faulting, and regional metamorphism. The presence of sillimanite suggests a high-grade regional metamorphism of 700 °C with pressures 4 to 5 kb (Volkert, 1996). A number of igneous events emplaced hornblende granite, quartz syenite, quartz monzonite, syenite, alaskite, and biotite granite. Their distinctly crystalline granitic texture indicates a subcrustal crystallization process. Insitu granitization had also taken place (Volkert, 1996). The result of these and crustal

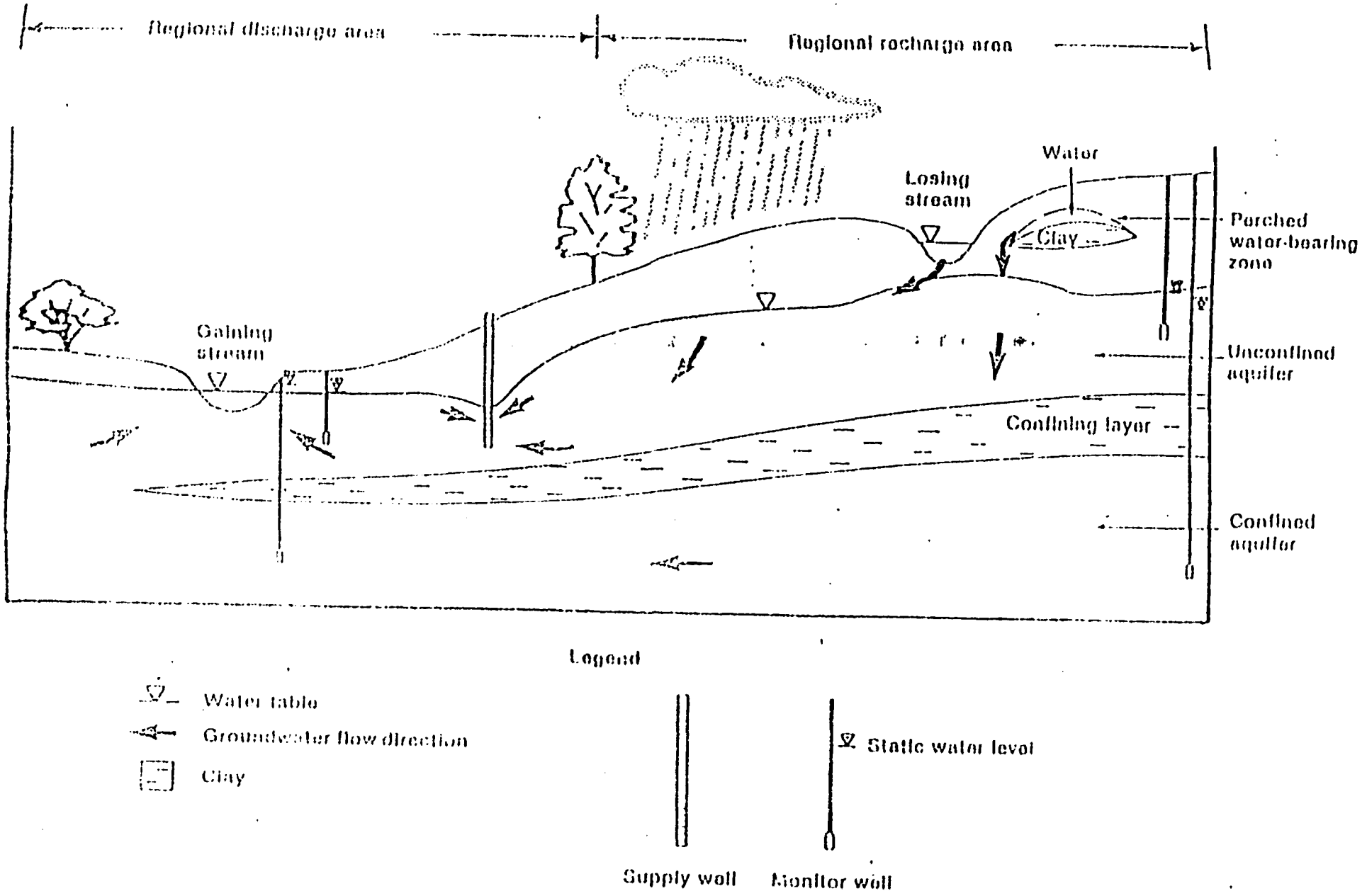
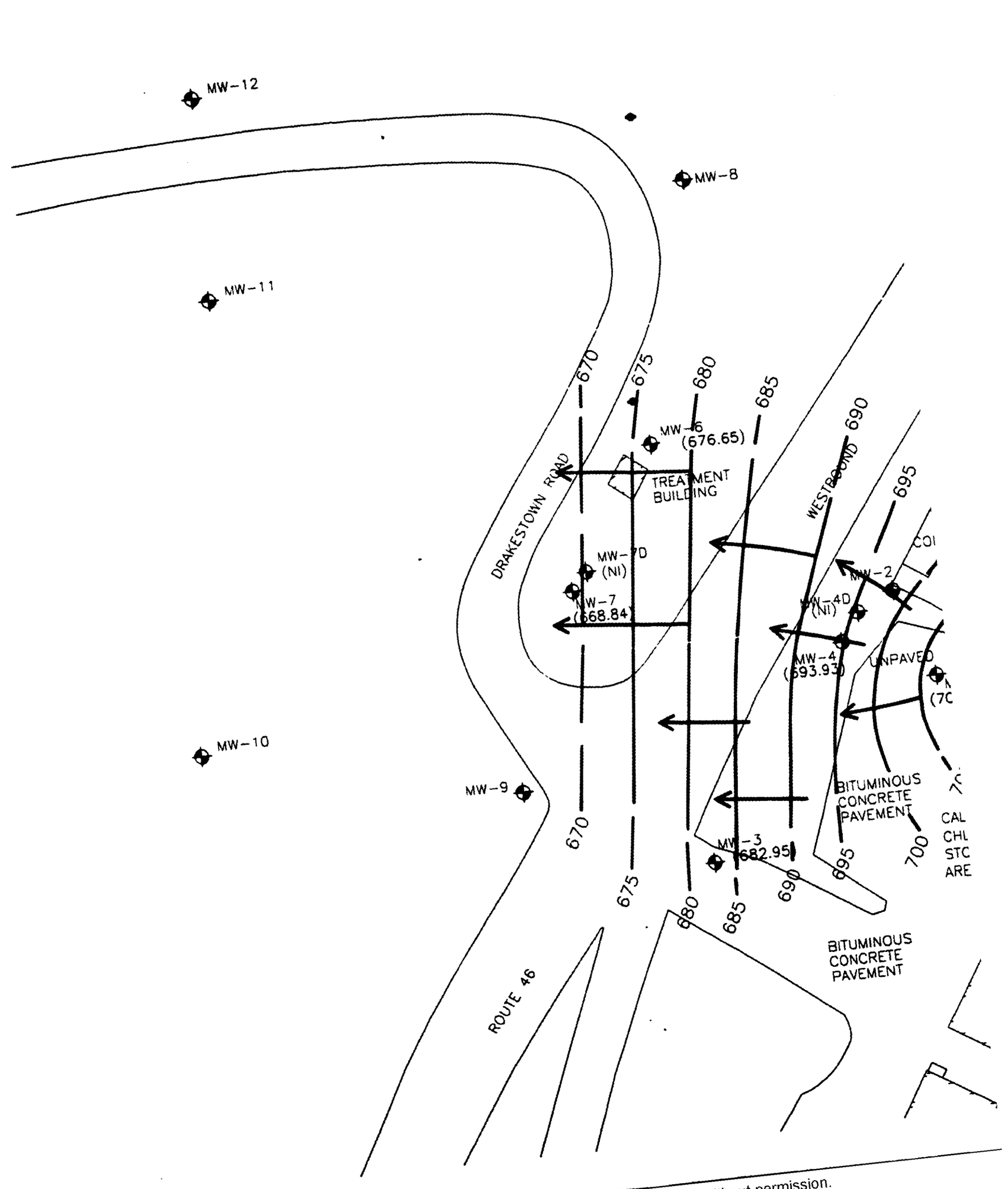
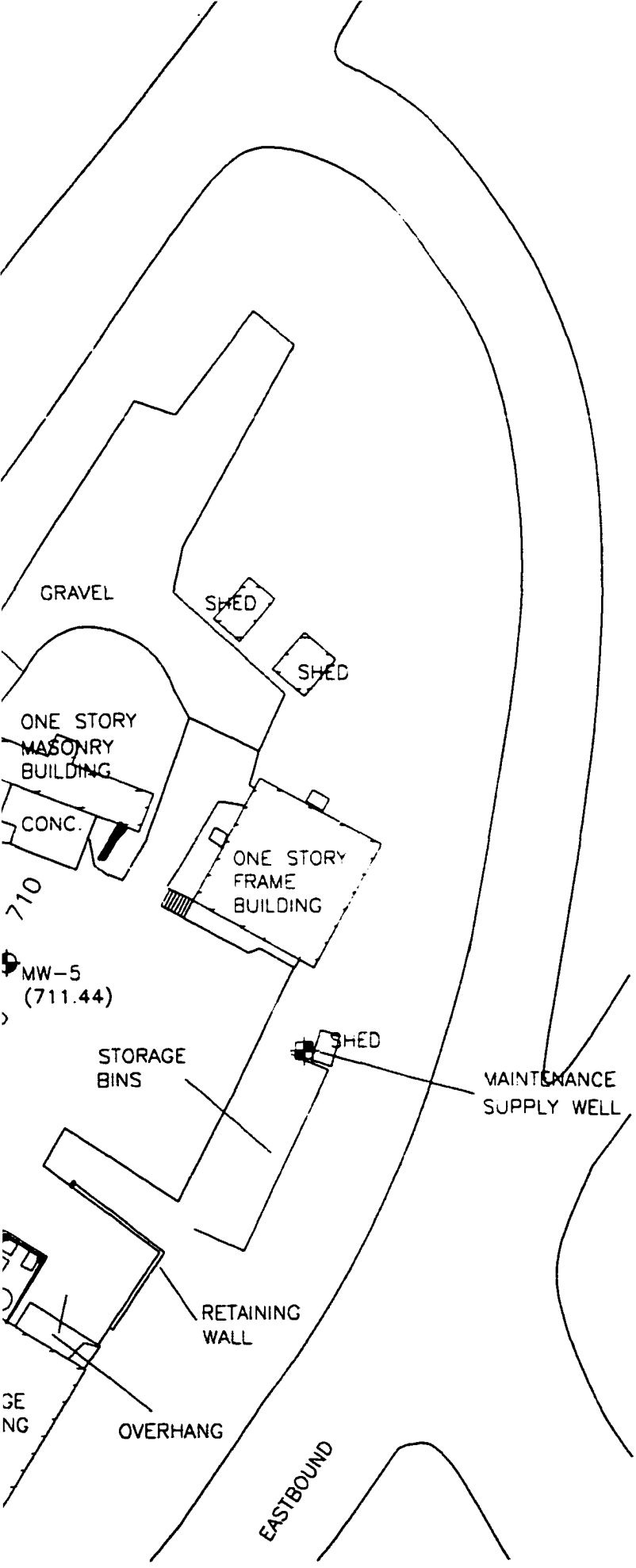


Figure 4.--Circulation of Groundwater From Regional Recharge Area to Regional Discharge Area





N

LEGEND

MW-1 (708.94)	SHALLOW MONITORING WELL AND ELEVATION OF WATER TABLE IN FT AMSL
MW-4D	DEEP MONITORING WELL
(FT AMSL)	FEET ABOVE MEAN SEA LEVEL
690	LINE OF EQUAL ELEVATION OF WATER TABLE (FT AMSL)
←	DIRECTION OF HORIZONTAL GROUND WATER FLOW

NOTE: HYDRAULIC GRADIENT = 0.23 TO 0.40 FEET/FEET

NOTE: MW-10, MW-11, MW-12 ARE NOT TO SCALE.

SCALE

50 0 50

(IN FEET)
1 inch = 50 feet

processes formed a coarse grained gneiss (Lucey, 1972). As implied by Volkert (1996), "besides forming the Highlands, the Precambrian rocks are the basement on which the Piedmont Plain sediments were deposited." The age of the crystalline basement is about 1.3 b.y. as determined by U/Pb, Pb/Pb isochrons (Volkert, 1996). Figure 6 is a geologic column of the area. In New Jersey, sediments some three thousand feet in thickness were deposited during the early-to-mid Paleozoic Era (Cambrian, through Devonian periods) (Volkert, 1996). Rocks from the last three periods of the Paleozoic are not present in New Jersey, but rather are found in Pennsylvania to the northwest and west (Lucey, 1972). It is thought that Mississippian and Pennsylvanian sediments were once present but were removed through erosion. No Permian formations have been found in New Jersey (Wilber and Johnson, 1940).

"At the beginning of the Cambrian Period, the eroded Precambrian surface was covered with rock debris" (Tedrow, 1986). As the sea slowly advanced, the debris was gradually washed, rounded and sorted. "During sorting, the finer material settled in the calm deep water of the basin, which extended from Newfoundland, through northwest New Jersey, and southward to Alabama" (Wilber and Johnson, 1940), while the coarser material was deposited near shore where the currents were strong (Tedrow, 1986). The sands and gravels which accumulated during this time constitute the Hardyston Quartzite. The thickness of this formation ranges from a few feet to 200 feet or more (Wilber and Johnson, 1940). As the name implies, this formation is for the most part a quartzite, but some lenses of conglomerate appear near the base of the formation. The conglomerate

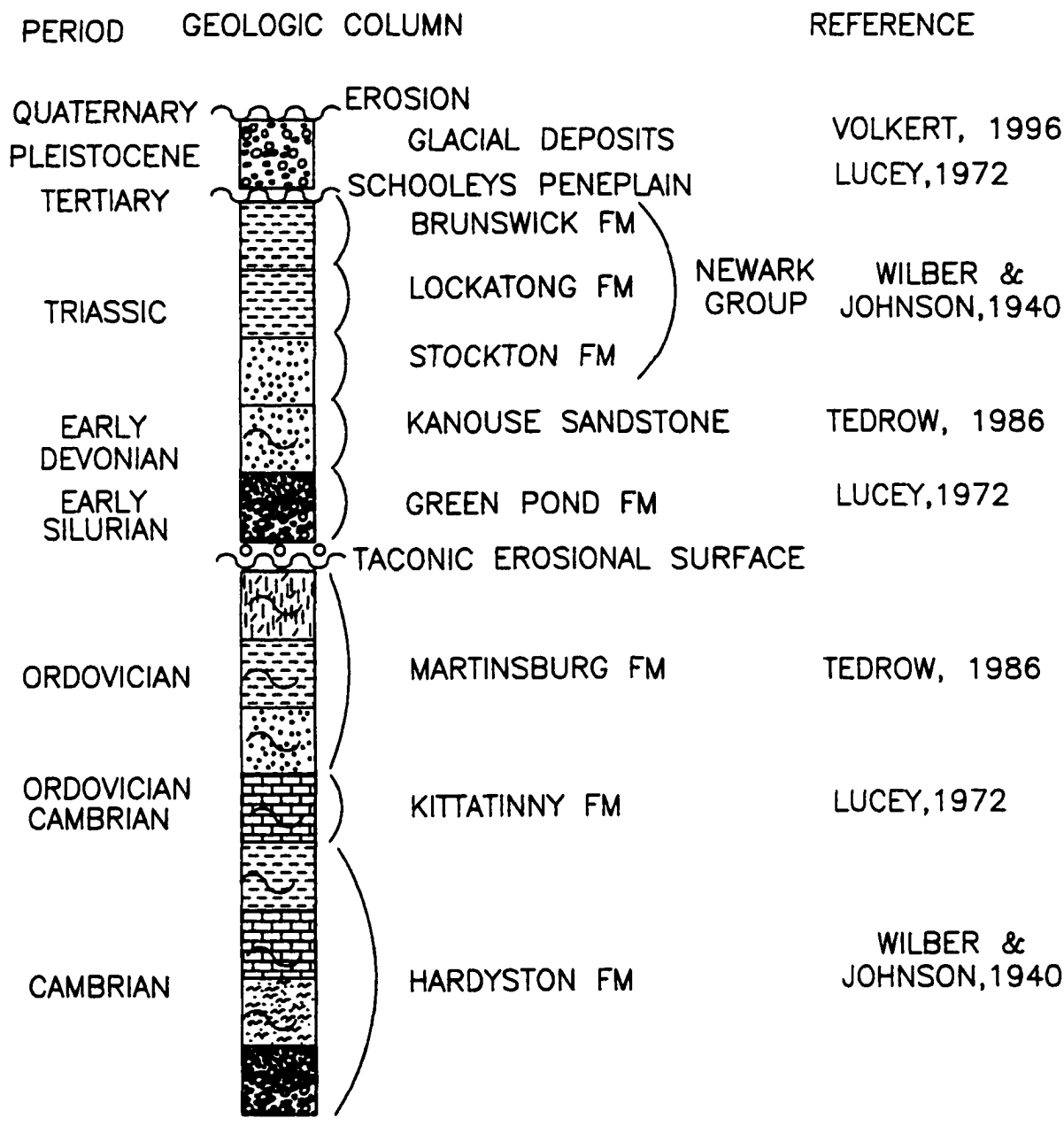


FIGURE 6

contains pebbles of radiometric dated Precambrian material (quartz, feldspar, and rock cobbles of gneiss and shale) (Lucey, 1972).

"During the later part of the Cambrian and the beginning of the Ordovician Periods, warm shallow seas prevailed throughout most of the basin" (Tedrow, 1986). The abundant lime organisms and the appropriate temperature (ranging from 8° to 12° C) conditions of the quiet shallow seas resulted in the precipitation of calcium carbonate which formed limestone, now called the Kittatinny Formation (Lucey, 1972), which is shown to overlay the Hardyston formation in figure 6.

During the Ordovician Period, following uplift and a long period of erosion (approximately 15 to 20 m.y.), the sea again invaded Morris County (Lucey, 1972). The streams which flowed into the sea carried large amounts of fine silt and sand, which were deposited, subsequently creating a series of sandstones, shales and slates called the Martinsburg Formation (Tedrow, 1986). The Ordovician period concluded with the Taconic Orogeny. This event caused both folding and faulting of the Cambrian and Ordovician sediments, as well as the basement rocks (Wilber and Johnson, 1940).

By early Silurian the changes that had been brought about by the Taconic Orogeny were already greatly modified by erosion (Lucey, 1972). Northern New Jersey was gradually covered by an encroaching sea whose shoreline was variable (Tedrow, 1986). Rivers and streams flowing from the crystalline Highlands reduced the quartz to

fine sand and well-rounded small pebbles, producing the Green Pond Conglomerate (Ratchliffe, 1980). The thickness of this formation ranges from 1,200 to 1,500 feet, thinning to the northeast and southwest (Wilber and Johnson, 1940). As described by Lucey (1972), "this formation is a coarse, highly siliceous conglomerate interbedded with, and grading upward into, quartzite and sandstone."

"The beginning of Devonian period saw a narrow sea extending itself across Northwestern New Jersey" (Tedrow, 1986). The Morris County area was higher in elevation than the Sussex County area; however, the sea invaded the region in middle Devonian Period and sandy sediments were laid down, forming the Kanouse sandstone, having a thickness of approximately 215 feet (Kilian, 1976). The Kanouse sandstone was described by Lucey (1972) as "a thickly bedded, fine-grained conglomerate below and thinner bedded greenish sandstone above."

Following the Devonian Period, there is evidence of Triassic sediments (Tedrow, 1986). In the upper Triassic, widespread earth movement occurred affecting the Morris County region (Lucey, 1972). During this orogeny, the Highlands as a whole, including the crystalline basement, was uplifted, while the areas to the east of the Highlands were relatively depressed, creating a horst and graben topography. This topographic pattern formed a series of discontinuous intermontane basins from Nova Scotia in Canada, south to North Carolina in the United States (Tedrow, 1986). "The present Piedmont region of New Jersey formed the northern end of one of these basins and extended from

southeastern New York to New Jersey, southwest across Pennsylvania and Maryland into Virginia" (Lucey, 1972). Because of the characteristic red color (due to oxidation) and general absence of organic matter in the sediments, the depositional environment is interpreted to have reflected an arid climate with seasonal torrential rains. Debris was carried from the higher areas and spread in broad alluvial fans over the adjacent plains. The sediments deposited during this time have been referred as the Newark Group. On the basis of lithologic character the strata of the Newark Group in New Jersey have been divided into three parts, as follows: a) the Stockton formation- consisting of light-colored arkosic sandstone and conglomerate with interbedded red sandstone and shale. Its thickness is estimated at 3,000 feet; b) the Lockatong formation- consisting of black shale, hard massive, dark argillite flagstone. The formation has an estimated thickness of 3,500 feet; c) Brunswick formation- consisting of soft red shale with some interbedded sandstone. Its thickness has been estimated at 8,000 feet (Wilber and Johnson, 1940).

"When the seasonal rains began, heavily laden streams flowed from the Highlands carrying sand, silt and clay" (Kilian, 1976). When the material flowed into the valley, of which Morris County was a part, the material was deposited, to subsequently form the Brunswick formation, with a thickness estimated at some 8,000 feet (Tedrow, 1986). At the end of the Triassic, movement along a series of northeast-southwest fractures brought the deposition to a close. The fractures formed a succession of long and narrow blocks, which were subsequently tilted to the northwest. The fractures still exhibit activity; seismic events (3.0 and less on the Richter scale) are frequently recorded (Ratcliffe et al.,

1987).

Marked erosion during the Tertiary Period of the Cenozoic formed the Schooleys peneplain. Following gentle uplift, the increased stream gradient resulted in deep erosion, carving out valleys in the underlying sediments (Lucey, 1972). Remnants of the Schooley Peneplain in Morris County include the crests of the Highlands, and the flat-topped Schooley Mountain in the west, from which the name of the peneplain was derived (Lucey, 1972).

During the Pleistocene four main continental glacial episodes occurred in North America. Only three of the four glacial advances reached New Jersey, the Kansan (oldest), Illinoan, and Wisconsin (youngest) (Lucey, 1972). "The evidence left from the Kansan sheet is patchy" (Tedrow, 1986). Scattered rocks and clayey till (tough, stony clay) are found in the uplands, usually the Highlands (Volkert, 1996). As stated by Tedrow, 1986, "the Illinoan stage has left more drift than the Kansan, but the evidence is still scattered. The material is composed of clayey gravel deposits, and leached and oxidized pebbles and boulders. The appearance of the material is due to the long exposure to the elements of weathering and erosion. This drift is found on hilltops and in low terraces along streams."

The Wisconsin ice sheet is the most recent and has left the most evidence of its passing. The southern extension of the ice during this stage is marked by terminal

moraine which crosses Morris County at Madison, Morristown, Dover, and Netcong (Lucey, 1972, and Ratchliffe, 1980). The moraine consists of a heterogeneous mixture of clay, sand, stones and boulders. A terminal moraine has been found, which is more or less discontinuous, broken by gaps, most of which mark places where meltwater streams existed (Lucey, 1972).

North and south of the moraine the rock surface is covered generally by drift deposits, both stratified and unstratified. The unstratified drift or till is an unsorted mixture of boulders, pebbles, sand and clay. The stratified drift is composed of beds of clay, sand and gravel, which, in the process of deposition, were sorted and deposited by streams fed by glacial melt water. (Lucey. 1972). It is assumed that none of the drift material was derived from regions north of New Jersey and that erosion did not exceed 25 feet in most places (Tedrow, 1986).

Nature of the Natural Soil Profile

A soil profile was never directly ascertained at the study site. However, based on the characteristics of geology, average rainfall, and average temperature, a reasonable set of assumptions was developed, and the soil profile of the study site was considered more like that of the regional soil profile.

The soils in the region consist of silt, silty clay and silty sand, usually containing

considerable rock fragments (USADSCC, 1976). Figure 7 is a map of the soil profile of the area. The soil at the study site is shown in such figure as AnB and described by USADSCC, 1976 as "formed in material weathered from gneiss and in glacial till. Typically these soils have a dark brown gravelly loam surface layer 11 inches thick. The subsoil from 11 to 17 inches is yellowish brown gravelly loam. At 32 to 44 inches is a firm and brittle fragipan that is strong brown gravelly sandy loam. The substratum from 44 to 99 inches is gravelly sandy loam and sandy loam." The B-horizon usually has a more coarse texture than the C-horizon. A horizon is defined as a component layer of soil, approximately parallel to the surface. Soils in this area are divided into four major horizons:

O horizon- Is the layer of organic matter on the surface of a mineral soil. This layer consists of decaying plant residues.

A horizon- Is the mineral horizon at the surface or just below O. This horizon is the one in which living organisms, such as worms and ants, are most active and therefore is marked by the accumulation of humus. The horizon may have lost one or more of soluble salts (such as $CaCO_3$, NaCl, $CaSO_4$), clay, and sesquioxides (iron and aluminum oxides), thought to be due to water leaching.

B horizon- Is the mineral horizon below A. The B horizon is in part a layer of gradations change from the overlying A to the underlying C horizon. The B horizon has distinctive characteristics as: (1) accumulation of clay, sesquioxides, humus, or some combination of these components; (2) by prismatic or block structure; (3) by deeper colors (yellow to red, denoting an oxidation state of iron -$Fe^{2+} \Rightarrow Fe^{3+} + e^-$-) than the A horizon; or (4) by

some combination of these. Combined A and B horizons are usually called solum, or true soil.

C horizon- Is the weathered rock material immediately beneath the solum. In most soils this material is presumed to be the parent material from which the overlying horizons are formed.

D horizon- Is the parent material (bedrock or sediment).

Figure 8 is a generalized soil profile.

Storage Tank and Fill Aggregate in Soil

The underground storage tank was excavated in 1996. During the excavation personnel performing the work maintained a drilling log. They described the following:

0 - 6" below ground surface Asphalt, Gravel

0'6" - 2'0" below ground surface Brown silt

2'0" - 5'0" below ground surface Quarry Process Gravel Fill

5'0" - 7'0" below ground surface Fine Brown sand with some Fine Gravel

7'0" - 10'0" below ground surface Red/Brown clay with silt

10'0" - 13'0" below ground surface Brown silt with fractured shale. The shale is a member of the Brunswick formation of the Newark Group.

Whereas regional profiles are helpful, when local releases take place it is

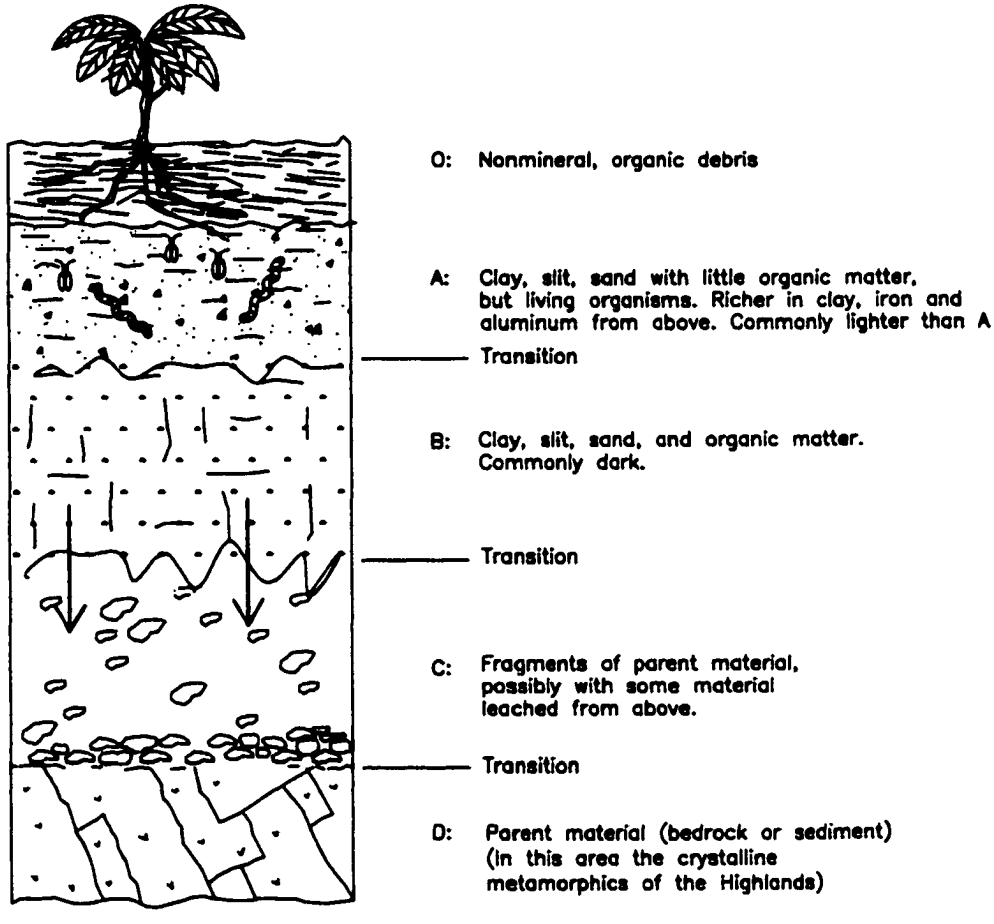
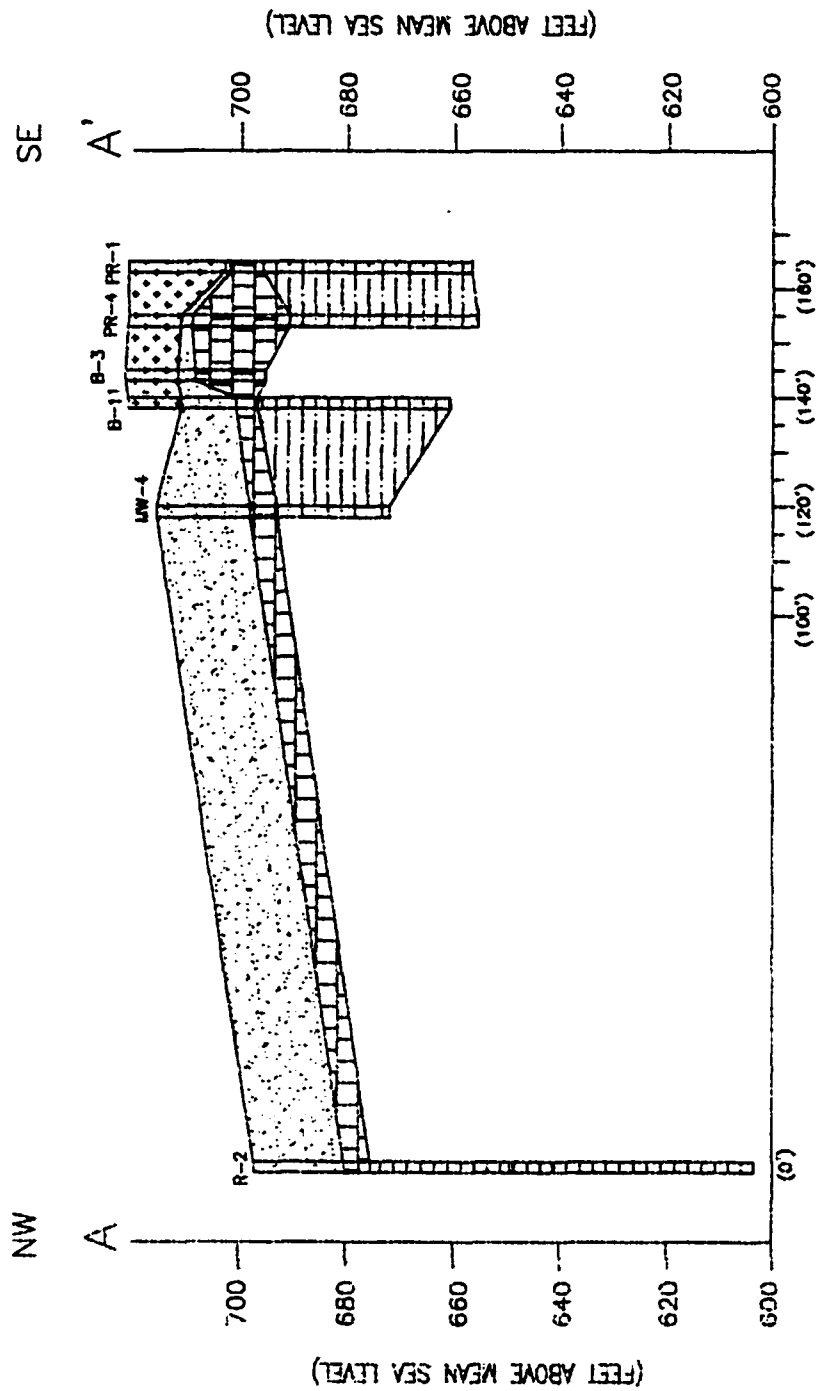


Figure 8 Soil Profile. This profile is a representation of a northern hemisphere middle latitude soil with an annual rain fall of approximately 40 inches per year under moderate acid conditions of pH range of 5.5 to 6.5.

necessary to drill for specific important details. The local geology of the study site has not been studied in detail, therefore, drilling has allowed a very important contribution to be made to the geology of the area.

The soils at the site are derived from both weathered bedrock and moraine presumably carried by the Wisconsin ice sheet (Husch and Goldstein, 1986, and USDASCC, 1976). The soils at the study site, as described by Banino et al., (1970) are typically yellow brown, orange brown and red brown (indicating the oxidation state of limonites). Some residual soils retain a banded structure, reflecting a residual structure of the parent gneiss. The soil at the study site was described by the geologists of Dresdner Robin Environmental as, mostly, medium to fine sand particles with some silty clay size sediments, ranging in thickness from approximately 6.5 feet (at monitoring well 10) to approximately 35 feet (at monitoring well 9). Figure 9 is a geological cross-section of the study site as determinant of water storage and movement. Other cross-sections are available in appendix 2. The soil at the study site can be divided into three groups: 1) a fill material composed mainly of coarse, medium, and fine sand, with trace silt; 2) underlying the fill material is a layer interpreted as glacial till, which is composed of medium to fine sand, with some silty clay, and trace coarse sand; 3) underlying the glacial till is a layer of saprolite, which is composed mainly of medium to fine sand.



CROSS SECTION A–A'

Capillary Forces

"In the capillary fringe, spaces between soil particles may be saturated by water rising from the water table under capillary forces. Certain chemicals like hydrocarbons that are lighter than water float on top of the water table. These floating chemicals form a separate phase that may move in different directions and at different rates than contaminants that are dissolved in the percolating recharge. Once dissolved contaminants reach the water table, they enter the ground-water flow system, which has both horizontal and vertical components. Below the water table, all pore spaces between soil particles are saturated" (Miller, 1993). At the study site capillary action is thought to have brought toxins more quickly to groundwater.

"In the water table the water is acted upon principally by the force of gravity and behaves according to the laws of groundwater flow. However, overlying soil is capable of permanently retaining considerable quantities of water within the particle interstices between the surface of the ground and the water table" (Meinzer, 1942). The permanent presence of water within this zone can be accounted for only by the existence of forces that counteract the mechanical effect of the force of gravity. These are known as capillary forces, and the water that is retained is called the soil moisture (Meinzer, 1942). "Soil moisture near the surface is subject to considerable seasonal variations due to evaporation and to the withdrawal of water through the roots of plants, and to rain fall" (McLaren and Peterson, 1967).

"The rise of water or other fluids in tubes or in interstices in rocks or soil may be considered to be caused by (1) the molecular attraction (adhesion) between solid material and the fluid, and (2) the surface tension of the fluid, an expression of the attraction (cohesion) between the molecules of the fluid" (Bear et al., 1993). "In every soil the capillary rise of the water takes place at a rate that decreases with increasing height of the capillary rise. To designate the degree to which the water and the air participate in the occupancy of the voids the following values are used" (Meinzer, 1942):

$G_a=e_a/e$ = degree of aeration = $1- e_a/e$ equation (1)

$G_s=e_w/e$ = degree of saturation = e_w/e equation (2)

where

e_a = the volume of air per unit of volume of solid

e_w = the volume of water per unit of volume of solid

$e=e_a+e_w$ = the void ratio, or the ratio between the volume occupied by the voids and the volume occupied by the solid

Since $e_a+e_w=e$ then $G_s+G_a=1$ equation (3)

As stated by Meinzer, 1942, "the rise of water into the voids of a dry sand represents the combined result of three physical causes: The molecular attraction between the sand grains and the water, the surface tension of the water, and the capacity of the water to resist hydrostatic tensile stresses of many atmospheres without losing its continuity."

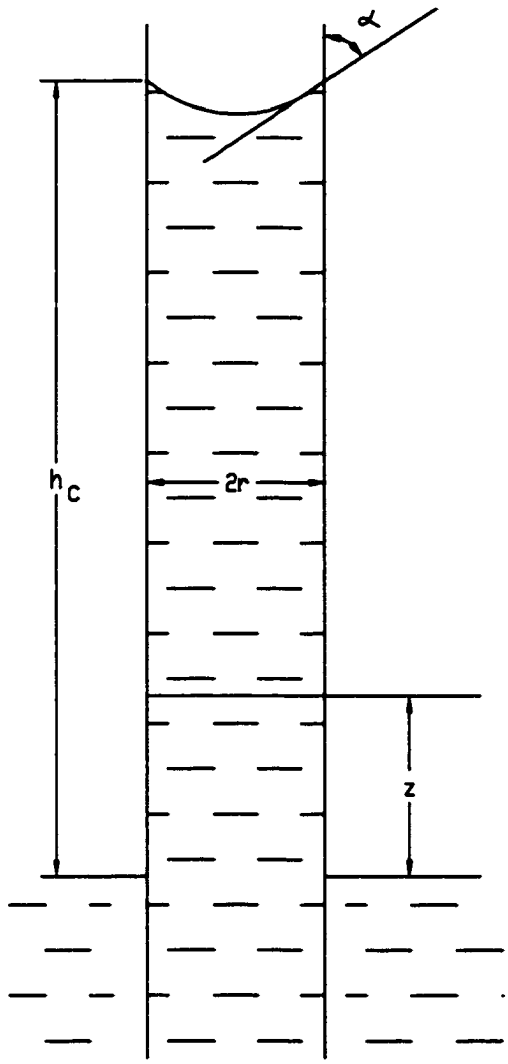
For water the estimated intensity of the molecular attraction ranges between 10,700 and 25,000 atmospheres. Meinzer, 1942, also concluded that "as the tensile strength of a liquid is, at least theoretically, identical with the force of attraction of the molecules on both sides of a section, it is not surprising that water is capable of resisting very high hydrostatic tensile stress without losing its continuity." He also stated that "the attraction exerted by the molecules of the walls of the tube or soil does not extend beyond an extremely small distance from the wall. This would keep water trapped in the soil, serving as a barrier for the less dense than water contaminants." At the study site the contaminants have persisted in the soil as the water table fluctuates throughout the year. As shown in figure 10, within the tube or soil the column of water terminates in a cup like depression, called meniscus (Meinzer, 1942).

Meinzer also stated that "the meniscus intersects the wall of the tube at an angle α, called the angle of contact. This angle varies with the chemical composition of the liquid and with the chemical composition of the walls of the tube or of the impurities that cover this wall." He also concluded that if the angle of contact is 0° a thin film of liquid is pulled up along the wall of the tube above the meniscus, and that for any value of the angle α the condition for the equilibrium of the column of water is $r^2\pi\gamma_T h_c = T_{ST}2r\pi\cos\alpha$ equation (4)

where

γ_T = unit weight of the water

T_{ST} = surface tension, both at a temperature T (in degrees centigrade)



Meniscus at the upper end of a column of water in a capillary tube. From meinzer, 1948

h_c = height of capillary rise
r = radius
z = variable height at depth
α = contact angle

FIGURE 10. CAPILLARY TUBE

From equation 4 we obtain

$h_c=(2T_{sT}/r\gamma_T)\cos\alpha$ equation (5)

Detailed studies have not been carried out at the site in terms of the influence of capillary forces on contaminants mobility. However, it is thought that capillarity has been in part responsible for the entrapment of contaminants in the soil.

The following table, from Meinzer, 1942, gives the magnitude of the surface tension of water in fractures of a gram per centimeter for different temperature T in degrees centigrade:

T	versus	T_{ST}
0°		0.0756
10°		0.0742
20°		0.0727

T	versus	T_{ST}
30°		0.0711
40°		0.0695

For room temperature we have approximately $T_{ST}=T_S= 0.073$ gram per centimeter and $\gamma_T=\gamma_w=1$. Then from equation 5 we obtain

h_c (centimeters) $= (0.15/r)\cos\alpha$ equation (6)

where

h_c = height (centimeters) of capillary rise of water in a tube or of soil moisture in a soil

T_S = approximate surface tension of water at room temperature, 0.073 g/cc

r = radius (centimeters)

α= contact angle, or angle between the vertical wall of a capillary tube and the adjoining free water surface

γ_T = weight of water per unit volume at a temperature T (°C)

γ_w = approximate unit weight of water, equal to 1 g/cc or 62.4 pounds per cubic feet (values sufficiently accurate for practical purposes)

The height h_c of capillary rise increases inversely as the diameter 2r of the tubes, and it also increases in direct proportion to the cosine of the angle of contact α. Meinzer states that "laboratory experience regarding the influence of the porosity on the coefficient of permeability of sands shows that the effective average width, 2r, of the capillary passages increases approximately in simple proportion to the void ratio e." On the basis of that experience he obtained for the average radius of the capillaries in the soil equation

$r=B_e(D_{10})^2$ equation (7)

where

B_e = an empirical factor depending on the shape of the grains of the sand

D_{10} = Allen Hazen's effective size (the grain-size diameter at which 10% by weight of the soil particles are finer and 90% are coarser).

Introducing this value into equation 6, then

$h_c=(0.15/B_eD_{10})\cos\alpha = C/eD_{10}$

in which $C=(0.15/B)\cos\alpha$

The value of the factor C depends on the shape of the grains and on the angle of contact α, which in turn depends on the amount and the kind of impurities that cover the surface of the grains.

The following table, from Meinzer shows the different fractions of sand at temperature of 17 °C:

Grain size, mm	versus	h_c, centimeters
5-2		2.5
2-1		6.5
1-0.5		13.1
0.5-0.2		24.6
0.2-0.1		42.8
0.1-0.05		105.5
0.05-0.02		200

The porosity of sands tested ranged between narrow limits of 40.1 and 41.8 percent and averaged 41 percent. The corresponding void ratio is 0.69.

This table shows that the height of capillary rise increases very nearly inversely to the first power of the grain size. Meinzer concluded that "the finer the soil the longer it takes for the rising water level to arrive in the vicinity of its ultimate position, at a height h_c above the free water level." He also concluded that this is due to the fact that the permeability of the soil decreases with the square of the effective grain size, and that "in order to evaluate the influence of permeability on the speed of the capillary rise we assume, as a first approximation, which the state of complete capillary saturation extends to the very top of the moistened zone of the soil." The validity of Darcy's law was also assumed, $V=Ki$ equation (9)

where

V= the discharge velocity

K= the coefficient of permeability, or the discharge velocity for i=1

i= the hydraulic gradient

"If a water particle travels along a flow line through a distance l, the corresponding hydraulic gradient depends on the hydrostatic head at the two ends of the line of travel" (Bear et al., 1993). Meinzer said that "the hydrostatic head for any point of the flow line is equal to the height to which the water level rises at that point in a piezometric tube above an arbitrarily chosen reference level, for instance, the level of the adjoining free water surface." He also concluded that "the rise of the height is also equal to the algebraic sum of the height of the point above the reference level and the stress in the water at that point, expressed by the height of a column of water with a cross section

equal to unity, whose weight is equal the stress in the water, and that the height of a column of water equivalent to a pressure in the water is positive, and the height equivalent to a tension in the water is negative." According to Meinzer, 1942, "if the hydrostatic head at the two ends of the path with length ℓ is equal to h_1 and h_2 respectively, the hydraulic gradient is equal to $i=(h_1-h_2)/\ell$" equation (10).

Although some gasoline compounds have traveled downgradient from the source area, gasoline has not moved away from such area. This indicates that gasoline is hydrophobic and does not sit on top of the water table, and consequently will not travel with groundwater. Instead, capillary forces keep gasoline trapped, and capillary pore spaces serve as a storage. This facilitates the degradation of the toxins at the study site. As discussed further on in the text, the capillary effects are believed to have played and important role in the movement of the contaminants at the study site.

Meteorological Data for the Study Site

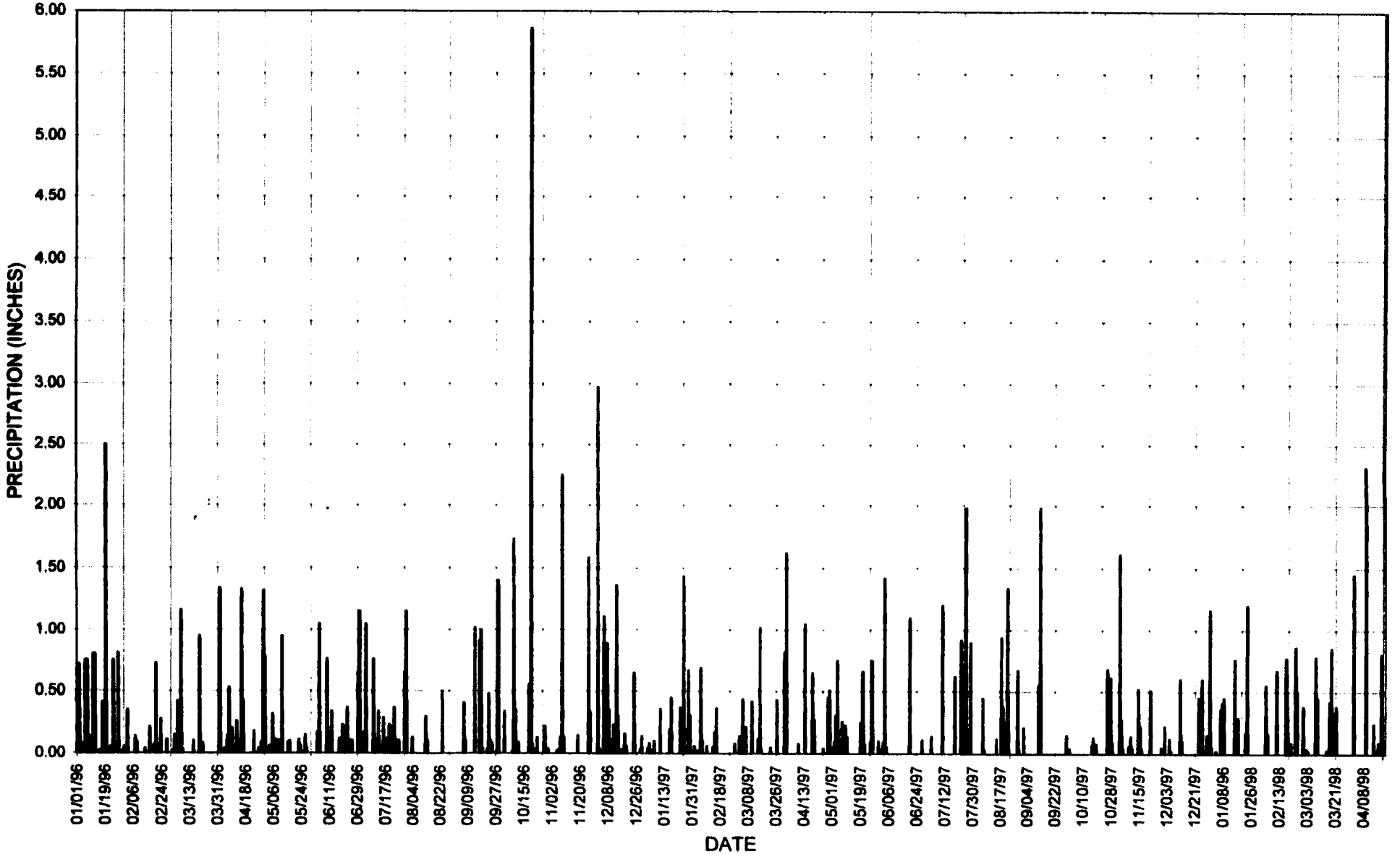
The area's climate was described by Kilian (1976) who thought that it conformed with the entire Middle Atlantic Seaboard; it may be classified as a modified Continental-type Climate. The prevailing westerly winds are modified by air masses originating over the ocean and moving on shore. Gill and Vecchioli, 1965, indicated that "the winters are controlled by polar continental air masses, and summers by tropical air masses. Although

maritime in origin, the patterns display long continental trajectories over very warm land masses before reaching New Jersey."

Morris County receives part of its precipitation from storms that cross the Great Lakes region and pass down the Saint Lawrence Valley (LVCC, 1998). The heaviest general rains, however, are produced by coastal storms of tropical origin (Gill and Vecchioli, 1965). Precipitation throughout the county averages more than 48 inches annually (U.S. Weather Bureau, 1959). Table 2 is a chart showing precipitation at the study site from 01/10/96 through 04/08/98. Precipitation is important in terms of contaminants transport and fate. Much precipitation would facilitate transport mechanisms for toxins, while little precipitation would retard their movement. At the study site precipitation has played an important role in the retardation of contaminants since precipitation has been approximately 48 inches per year, including precipitation from storms, where surface runoff accounts for some loss in the water budget of the area.

As previously stated, groundwater flow at the study site is found to be westerly. Most of the water comes from higher elevations by means of subsurface movement. However, precipitation plays a dominant role in the recharge of the aquifer. Hackettstown receives approximately 48 inches of precipitation every year. The yearly average of snow fall at the study site is about 45 inches. While some of the precipitation leaves the study site as surface runoff, a portion seeps through the porous layers. Groundwater flow at the study site takes place in both the overlying unconsolidated

Table 2
1996-1998 PRECIPITATION DATA
NJDOT- HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY



ground cover and the highly fractured bedrock. The overburden at the study site consists of a layer of saprolite, overlain by a layer of glacial till, which is overlain by a layer of fill material. Its physical nature impedes flow. The thickness of the overburden ranges from approximately 6.5 feet to about 35 feet.

AQUIFER CHARACTERISTICS

Characterizing the hydrogeologic properties of fractured bedrock aquifers is a complex and challenging task. "Diverse research efforts have ranged from laboratory-scale studies of discrete fractures to field-scale studies of fracture networks to basin-scale studies or regional groundwater systems" (Wang, 1991). "In field-scale investigations, three-dimensional fluid transport through a heterogeneous network of fractures is cumbersome to describe in detail and often requires multidisciplinary approaches consisting of drilling and sampling, surface geophysics, borehole geophysics, geologic mapping, and pumping and tracer tests" (Morin, 1997).

"An aquifer performs two important functions; a storage function and a conduit function. The interstices of a water-bearing formation act as storage sites and are part of a network of conduits. Groundwater is constantly moving through these conduits under the local hydraulic gradient" (Driscoll, 1986).

At Hackettstown there is good natural drainage at the site due to topography relief

and infiltration. The water table fluctuates annually between approximately 4 feet below ground surface (approximately 1 foot after a storm) and approximately 60 feet below ground surface. Appendix 3 is a table showing the water level elevation and amount of pure product (gasoline) measurements at the study site.

"Pumping tests provide hydraulic means of evaluating the continuity of bedding fractures and determining their hydraulic parameters (transmissivity or hydraulic aperture and storability). The conductivity and storage coefficients are especially important because they define the hydraulic characteristics of a water-bearing formation" (Freeze and Cherry, 1979). The coefficient of transmissivity indicates how fast water will move through the formation, and the coefficient of storage indicates how much can be removed by pumping or draining. A pumping test was performed at the study site to characterize the physical properties of the aquifer. Table 3 is a summary of results of well tests at the study site. More details are available in appendix 4.

At Hackettstown, hydraulic inactive fractures were easily recognized due to red, orange, and black oxidation/reduction staining along the fractures, as opposed to active fractures, which would show no oxidation effects. Near-vertical and horizontal fractures were recognized throughout the profile during collection of the column sample. Some crosscutting fractures (30° to 60°) were observed at some corings. Fracture spacing varied from 0.25 to 6 inches. Water movement through fractured bedrock is considerably slower than in unconsolidated material. At the study site permeability has been calculated to be

TABLE 3

SUMMARY OF RESULTS OF WELL TESTS
NJDOT HACKETTSTOWN FACILITY AND VICINITY

Wells Tested	Type of Test	Median of Computed Horizontal Hydraulic Conductivity (ft/day)	Range in Computed Storativities gpm
R-1	Pumping	1.2	$2.4X10^{-5}$ - $4.0X10^{-2}$
R-2	Pumping	0.2	**
R-2	Slug	0.1	**
R-3	Pumping	1.1	$7.1X10^{-4}$ - $1.8X10^{-2}$
MW-4D	Pumping	0.8	$4.6X10^{-5}$ - $3.5X10^{-2}$
MW-7D	Pumping	1.2	$8.1X10^{-6}$ - $1.9X10^{-2}$
MW-10	Slug	13.2	**
MW-11	Slug	2.7	**

** Storativity could not be reliably computed with method of analysis used.
gpm Gallons per minute.

0.5 to 3.0 ft/day, suggesting that water, as well as the contaminants would move at a rate of about 0.5 ft/day or less through the fractured bedrock layers, affording benzene and toluene opportunity to biodegrade before reaching the nearby populated areas.

Water Table Elevations

Water table fluctuations promote vertical spreading of hydrocarbons. "Free liquid hydrocarbons associated with the capillary zone will move downward as the water table drops, leaving residual liquid in the expanded unsaturated zone above the repositioned water table" (API, 1989). In an unsaturated soil the larger pores are filled with air, and numerous air-water interfaces exist (Meinzer, 1942). A subsequent rise of the water table will cause the capillary zone and associated free liquid hydrocarbons to move upward (Freeze and Cherry, 1986; and Palmer and Johnson, 1989). "Residual hydrocarbons in the unsaturated zone can be remobilized by rising free liquid hydrocarbons, causing lateral spreading at a different elevation. Further, a residual liquid phase can remain in the saturated zone below the repositioned water table" (API 1989). At the study site subsequent rise and fall of the water table has been interpreted to be responsible for the entrapment of contaminants at different monitoring wells.

Movement of Contaminants

"Transport and fate assessments require interdisciplinary analyses and interpretations because the processes involved in these activities are naturally intertwined" (API, 1989). "In addition to a sound conceptual basis, integrating information on geologic, hydrologic, chemical, and biological processes into an effective contaminant transport evaluation requires data that are accurate, precise, and appropriate at the intended problem scale" (Suflita, 1989).

"The flow of groundwater in the natural environment is strongly dependent on the three-dimensional configuration of geologic deposits through which flow takes place" (Freeze and Cherry, 1979). Usually, the general direction of groundwater flow can be established on the basis of the local topography (use of topographic maps or aerial photos) and the presence of streams or rivers which act as groundwater discharge boundaries (Driscoll, 1986). "Geology provides us with a qualitative knowledge of the framework of flow, but it is physics and chemistry that provide the tools for quantitative analysis" (Freeze and Cherry, 1979). Groundwater flow at the study site is westerly based on topography and piezometer measurements.

Hydraulic conductivities can be measured both in the laboratory and in the field. "Slug tests, aquifer tests, and flow net analyses are field methods that provide increasing scales of measurement" (Palmer and Johnson, 1989). A slug test was done at the study

site and the results are shown in appendix 4.

"Slug tests are the most common method for obtaining hydraulic conductivity in the field" (Cooper et al., 1967). These tests are conducted by instantaneously changing the hydraulic head within a well and measuring its return to the static level. Several techniques used for analyzing slug test data are described by Hvorslev (1951) and Cooper et al. (1967).

Released liquid hydrocarbons tend to move downward through the unsaturated zone in response to gravity. "As hydrocarbon migrates through the soils a significant portion of the hydrocarbon is lost to residual saturation and moves vertically downward around the water filled pores until it encounters the capillary fringe" (Driscoll, 1986). "When immiscible fluids reached the capillary fringe, their behavior is dictated by the fluids' density relative to water" (Schwille, 1984). Some horizontal spreading will also occur within this zone because of attractive forces between the liquid hydrocarbon and solid granular surfaces (API, 1989). Horizontal spreading at the study site is thought to be limited. This is based on laboratories results from side gradient monitoring wells.

Once in the aquifer, the primary driving force for contaminant movement is created by the hydraulic gradient that produces groundwater flow. "Contaminants entering the groundwater system are thus carried downgradient, forming a contaminant plume. This type of contaminant movement is termed 'advection' " (Driscoll, 1986). At

the study site the plume has been modeled to be approximately 1,500 feet downgradient from the source area. Downward and lateral migration of the free liquid hydrocarbons takes place at different speeds, depending on the rate and volume of the hydrocarbon release, density of the liquid hydrocarbons, porosity of the soil profile, and the attractive forces between water and the hydrocarbon fluid (API, 1989). "Contaminants move rapidly along the layers with higher permeability and more slowly along the lower permeability layers" (Freeze and Cherry, 1979). Also, "if a solute undergoes chemical reaction while being transported, its rate of movement may be substantially less than the average rate of groundwater flow" (Palmer and Johnson, 1989). Contaminants with lower retardation factors are transported greater distances over a given time period than contaminants with larger retardation factors. At the study site MTBE (with a retardation factor of approximately 1) has been detected further from the source area than toluene and benzene (both with a retardation factor of approximately 1.2).

K_{oc}, or the adsorption coefficient, is the ratio of the amount of a chemical adsorbed per unit weight of organic carbon in the soil or sediment to the concentration of the chemical in solution at equilibrium. According to ATSDR (1998a), "benzene, with an organic carbon sorption coefficient (K_{oc}) value of 1.8-1.9, would be considered to be highly mobile." However, because of biodegrability, benzene is not expected to survive far from the source area. Toluene, on the other hand, with an organic carbon-water partition coefficient (K_{oc}) of 2.25, is thought to be moderately retarded by adsorption to soils rich in organic matter, but is thought to readily leach from soils with low organic

content (Wilson et al., 1981). Even though the soil description at the study site does not present an organic-rich environment, the clay content at the site will slow the movement of the contaminants, allowing biodegradation to take place. MTBE is also thought to have a little tendency to sorb to soil particles, suggesting a considerable mobility. MTBE has been detected in both monitoring Wells 10 and 11. However, its low concentration (a maximum of 0.67 ppm), along with its small tendency to sorb to soil particles suggests that biodegradation of MTBE was a likely process at the study site. This is subject to a more detailed study.

"A free liquid hydrocarbon plume will develop if the hydrocarbon release exceeds the adsorptive capacity of sediments in the unsaturated zone" (Freeze and Cherry, 1979). "A plume will migrate by gravity in the direction of groundwater flow toward the water table and into any subsurface structure open to the atmosphere" (Driscoll, 1986). The size of the free liquid hydrocarbon plume is strongly affected by the release volume, release rate, porosity of the earth material, hydraulic conductivity, and the slope of the water table (API, 1989). The release volume at the study site has not been established, but Mills (1996) has estimated a release rate of approximately 0.7 gallons per day. The details of the aquifer characteristics at the study site are available in appendix 4. Additional modeling is ongoing at the present time to establish the size of the pollution plume.

If the contaminant solution entering the flow regime has the same density as the

groundwater, the contaminant plume will spread in a shallow zone close to the water table (Freeze and Cherry, 1979). If the contaminant solution is considerably more dense than the groundwater, the plume will sink steeply downward into the groundwater flow system. "Prediction of the contaminant migration patterns requires accurate knowledge of the density of the contaminant as well as that of the groundwater" (API, 1989). At the study site the contaminants are hydrocarbon by products, which are mostly insoluble and less dense than water, and known to travel at different velocities.

"A portion of the contaminant is adsorbed on the surface of the fracture and as diffusion occurs a portion is adsorbed in the matrix" (Driscoll, 1986). "The combined effect of adsorption on the fracture surface and adsorption in the matrix is to cause the contaminant mass in the fracture to be retarded relative to the advance that would occur in the absence of adsorption" (API, 1989). Once in the aquifer, different contaminants in the same plume may travel at different velocities depending on how they react with the geologic medium (Freeze and Cherry, 1979). As stated previously, results from several laboratories have shown that MTBE travels more rapidly than either benzene or toluene.

Fractured rocks can have both primary and secondary porosity. Primary porosity is the pore space formed at the time of deposition and diagenesis of the rock mass (Wilber and Johnson, 1940). Secondary porosity is the pore space formed as a result of fracture of the rock (Freeze and Cherry, 1979). The transport mechanisms in fractured rocks are advection and dispersion. "Advection takes place only along the fractures" (Driscoll,

1986). "Dispersion takes place within fractured rocks as a result of: 1) mixing at fracture intersections; 2) variations in aperture across the width of the fracture; 3) variations in aperture width along stream lines; 4) molecular diffusion into microfractures penetrating the interfracture blocks; and 5) molecular diffusion into interfracture porous matrix blocks" (Wilber and Johnson, 1940). The movement of hydrocarbon contaminants through fractured bedrock at the study site has not been established. More delineation coring would be necessary for this purpose. However, this last mechanisms is thought to be responsible for the movement of the contaminants through bedrock at the study site.

The rate of movement of the contaminant will depend on:

Groundwater gradient.

Viscosity of the compound.

Relative permeability of the formation to the compound, which is a function of the relative water/hydrocarbon saturation of the formation.

Geologic controls such as orientation of secondary porosity or changes in formation permeability.

The movement of the hydrocarbon on the water table is controlled by several factors. "Two major factors controlling movement are capillary effects and relative permeability" (Freeze and Cherry, 1986).

The capillary effects are believed to have played an important role in the

movement of the contaminants at the study site. The rise and fall of the water table has been very important in terms of contaminant entrapment. Permeability at the study site has been calculated to be 0.5 to 3.0 ft/day. Hydraulic gradient averages approximately 0.213, and porosity ranges from 0.01 to 0.10. Although the plume at the study site has been estimated, the rate of movement of the contaminants has been more difficult to determine.

The Study Site

Although much data was collected at the site, no formal nor overview report has been written. The following is a compendium of separate file memoranda, which I evaluated. Some were authored by me.

The study site (Hackettstown) is located in the New Jersey Highlands in Northwestern New Jersey, near the terminus of the southern edge of the Wisconsin sheet (Tedrow 1986, and Lucey, 1972). The bedrock in the vicinity of Hackettstown is mapped as the Byram Gneiss, a highly fractured grey granitic gneiss (Volkert et al., 1994). A northeast-southwest trending normal fault is mapped approximately 0.3 miles west of the site on the New Jersey Topographic series Geologic Overlay. Figure 11 is a geological map of the study site and its surrounding. A more detailed geologic geological map of the area is available in appendix 5.

According to the topography, the study site is located in an area of aquifer recharge. In a recharge area there is a component to the direction of groundwater flow near the surface that is more downward than lateral. A recharge area is defined as an area in which water is absorbed that eventually reaches the zone of saturation in one or more aquifers. In a discharge area there is a component to the direction of groundwater flow near the surface that is upward. A discharge area is defined as an area in which subsurface water, including both groundwater and vadose water, is discharged to the land

surface, to bodies of surface water, or to the atmosphere. In a recharge area, the water table usually lies at some depth; in a discharge area, it is usually at or very near the surface. As described by Dresdner Robin's geologists the aquifers consist of an overburden aquifer of an unknown thickness which is semi-confined by a fragipan layer that is known to impede the vertical migration of groundwater (USDASCC, 1976), and a bedrock aquifer. Regional groundwater flow in the overburden aquifer is to the west where it ultimately discharges to the Musconetcong River.

Geologic Structure and Control of Water Flow

Groundwater data from the area are also few. Therefore, I had to rely on general scenarios from other similar geological areas. I used the geology profile of the area to fit into work by Volkert (1994 and 1996).

In Morris County, folds are a major structural feature in the Highlands, and are dominated by northeast-trending, isoclinar, northwest overturned to upright antiforms and synforms that plunge gently to moderately to the northeast and less often to the southwest (Volkert, 1996). Less abundant are folds that are upright to overturned to the southwest and plunge to the north-northwest or to the south-southwest. Secondary folds are upright and plunge predominantly to the east. Folding occurs on all scales from microscopic to megascopic and at outcrop scale generally represents parsitic folds developed on the

limbs of larger regional folds (Volkert, 1996). Details on the geological structures of the area may be found in appendix 5. The complex geological history of the region is expressed in the polyphase deformation of the metasediments.

Faults are another major structural feature and are important in terms of rock integrity and groundwater control. They partition the Highlands into a mosaic of structural blocks of varying dimension and help create the overall northeast-southwest grain of the regional structure (Vorkert, 1996). Most of the faults in Morris County are northeast-trending, high angle, southeast-dipping normal faults (Gill and Vecchioli, 1965), and less often reverse faults (Vorkert, 1996). Most faults in the Highlands are characterized by retrograde mineral alteration in the form of epidote, chlorite, and less often, tremolite-actinolite that coats fractured surfaces that suggests multiple episodes of reactivation, the last being normal dip-slip movement related to Triassic rifting of eastern North America. (Vorkert, 1996).

As described by Volkert, 1996, "the Highlands' joints typically are planar, penetrative, moderate well formed, and moderately to steeply dipping. Their surfaces usually are unmineralized but occasionally, where utilized during tectonism, they may be coated with chlorite or epidote, and slickensided . Joint lengths are variable from outcrop to outcrop but usually on the order of several feet to a few tens of feet." Figure 12 is a Rose diagram showing joint orientation throughout the Highlands. At Hackettstown outcrops are rarely exposed, making it more difficult to predict the local joint pattern.

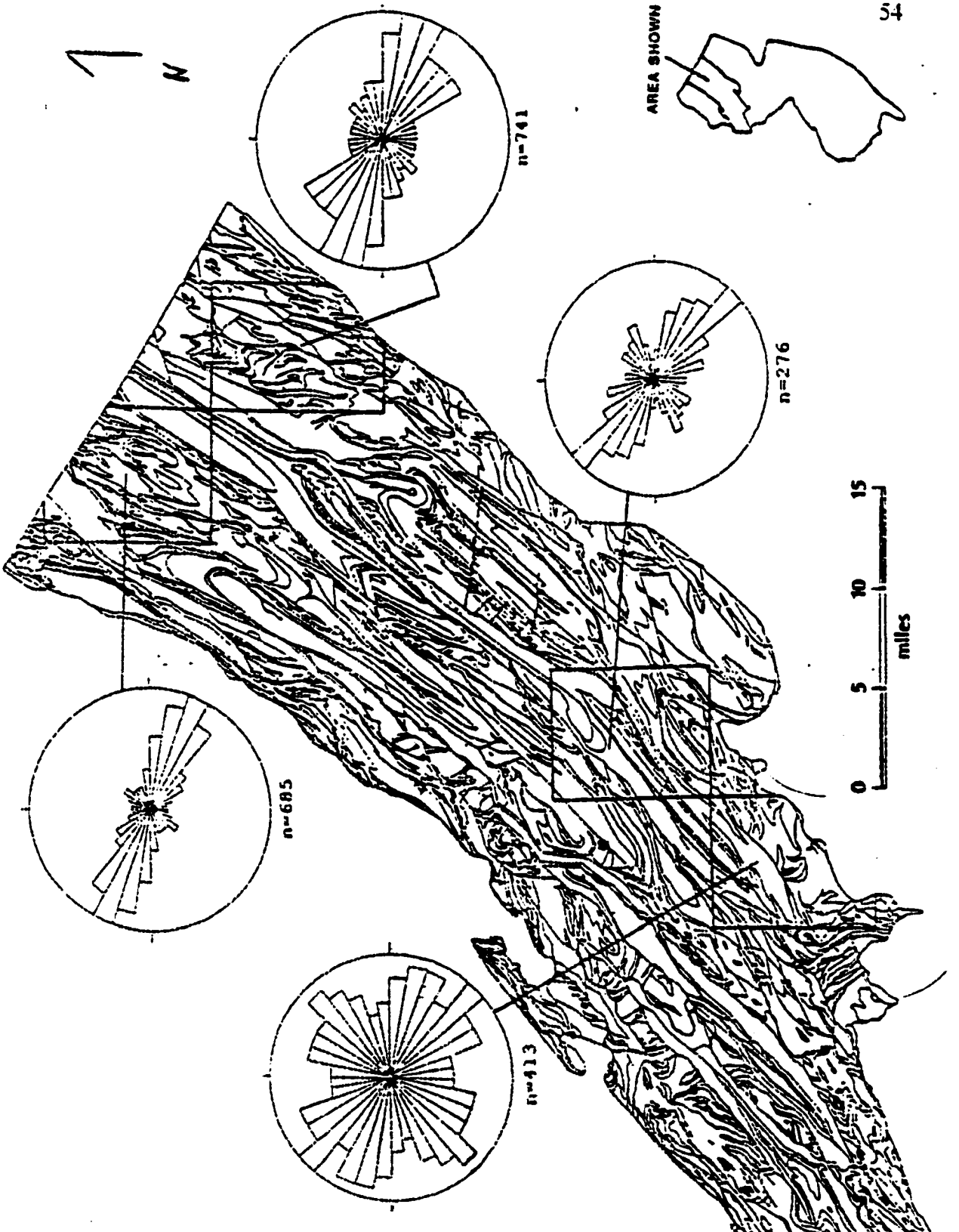


Figure 12: Rose diagrams of joint orientation from throught the Highlands. Adapted from Volkert et al., 1996

Fractures are thinner, more irregular, planar or anastomosing, discontinuous, and much more localized than joints, and may be open or mineralized and have dips that range from gentle to very steep (Volkert, 1994 and 1996). "Most fractures have widths of 1 /10th of an inch or less and are seldom traceable in outcrop over distances or more than a few tens to a few hundred feet. Hence, they are less important from a regional standpoint and are most significant from a local, site-specific one" (Volkert, 1996). Core samples at the study site indicate that fractures decrease with depth, slowing considerably the migration of contaminants. As observed in the core samples from the study site, the top 20 feet of bedrock showed a fracture spacing varying from approximately 0.25 to 4 inches. Core samples below 20 feet showed fracture spacing ranging from approximately 4 to 6 inches, with a gradual transition with depth. Core samples were taken to approximately 85 feet below ground surface.

Sampling Procedures for Groundwater

Sampling Methodology

Groundwater sampling was conducted in accordance with the New Jersey Department of Environmental Protection (NJDEP) "Field Sampling Procedures Manual." Sampling took place after the evacuation of three recharges of water from the well, and after the well recharged at least 90%, or within two hours from purging time, whichever

came first.

During the first round of sampling, the well suspected to be contaminated least was sampled first. Well head readings, using a Photoionization Detector (PID), were used to estimate the sampling order. During the subsequent sampling episodes, the least contaminated well was sampled first and the most contaminated well was sampled last. This was done to avoid the possibility of cross-contamination from equipment usage (such as water level indicator).

All sampling was performed using teflon bailers attached to approximately two feet of teflon coated stainless steel wire, which in turn was attached to polypropylene rope. The bailer was slowly submerged with care not to aerate the groundwater and then retrieved to be transferred into the appropriate containers. Sampling equipment was handled with new surgical gloves to prevent any potential contamination of the samples. Surgical gloves were continuously being replaced, insuring clean handling procedures. Trip blanks were supplied along with every shipment of sampling containers. Such containers prepared by the analytical laboratory, arrived at the site properly sealed within one day of their preparation. Duplicate samples were collected at a rate of one for every twenty samples, and a minimum of one per sampling episode at the study site.

Water samples were analyzed for volatile organics by purge and trap Gas-Chromatography/Mass Spectrometry (GC/MS) in accordance with EPA Method 624, and

for benzene, toluene, ethylbenzene and xylenes (BTEX) by GC-PID in accordance with EPA Methods 502.2 and 602. Water samples were also analyzed for petroleum hydrocarbons by infrared (IR) using EPA Method 418.1. Soil samples were analyzed for BTEX in accordance with EPA Method 8020A, and for petroleum hydrocarbons using the March 1990 NJDEP "Remedial Investigation Guide" Appendix A, page 52, and analyzed the EPA Method 418.1.

The following criteria were followed by the analytical laboratory:

1. Analyzed field samples, field blanks, and trip blanks.
2. GC/MS tune specifications-instrument performance check by Bromofluorobenzene (BFB) were performed.
3. GC/MS tuning frequency were performed very 12 hours.
4. GC/MS initial calibration was performed within 30 days before sample analysis and continuing calibration were performed within 12 hours of sample analysis.
5. Detection limits were as follows: Benzene (1.0 ug/L), Toluene (1.6 ug/L), MTBE (0.48 ug/L), Chloromethane (11.5 ug/L).

Saar and Banaszak (1993) stated that "no matter how carefully sampling is performed, ground water is subject to trauma resulting from the change of pressure, the presence of oxygen, and other factors. Several studies have shown that a major sector of data variability can be traced to who did the sampling. In an ideal world (for the data

user), all samples for a multi-year program would be obtained by the same trained persons and analyzed by one competent laboratory. In reality, changes in both the sampling staff and the laboratory are unavoidable." At the study site at least twelve different persons were involved in sampling over a period of three years. They also stated that "most laboratories are commercial operations that must balance scientific and business demands. Although your samples are the most important ones from your perspective, they are no different from hundreds of other samples from the laboratory's point of view. Therefore, a laboratory's average or usual performance is the proper basis for judging proficiency. Any laboratory can "shine its shoes" on the day of an audit or during the period when official performance evaluation samples are being analyzed. Unfortunately, most samples are not analyzed on such days." As previously stated, at least twelve different persons were involved in sampling at the study site, and official performance evaluation was minimal at the site. Therefore, I suggest that these factors might account for an estimated +/- 25% error on the sampling results.

Other factors that might affect the sampling results have been pointed out by Saar and Banaszak (1993) are the following:

1. Variability resulting from monitoring system setup (drilling fluids seeping into well, and improper well development).
2. Variability introduced during sampling (rate and duration of pumping, sampler and its effect on sample, and filtration, preservation and bottling).
3. Sampling variability (volatiles loss during pumping, solvents in pump lubricants such

as methylene chloride).

4. Variability introduced after analysis.

a) Incorrect calculations (wrong conversion factors, misplaced decimal place).

b) Reporting errors (errors in transcription, wrong units, mislabeled data sheets).

Morrison (2000) also provides some information regarding potential sampling errors. He stated the following: "volatile compounds are particularly sensitive to losses by degassing due to turbulence created by mechanical sampling devices such as bailers. Sampling procedures that represent potential sources of volatile organic compound loss include: 1) sampling with a bailer and aerating the sample during transfer from the bailer into the sample container; and 2) not placing the cap on the sampling container or immediately chilling the sample."

Agents of Concern Due to their Toxic Effects

The following is a list of constituents of concern at the site. The compounds selected were suggested by the New Jersey Department of Health to be used to assess the potential threats to public health and environmental quality.

- Benzene (gasoline component)
- Chloromethane (possible byproduct through in situ chemical reaction)
- Toluene (naturally occurring in crude oil or a refining product)
- Methyl tertiary butyl ether, MTBE, (gasoline additive)

Description of Agents of Concern

Benzene

Benzene is a colorless liquid with a sweet odor. Table 4 is a list of some chemical and physical characteristics of the compound. Benzene evaporates into air (vapor pressure -mm Hg- of 60 at 15 °C) quickly and is slightly soluble in water. "Benzene is highly flammable. Most people can begin to smell benzene in air at 1.5-4.7 parts per million (ppm) and smell benzene in water at 2 ppm" (ATSDR, 1998a). As reported by ATSDR (1998a), "most people can begin to taste benzene in water at 0.5-4.5 ppm. Benzene is ubiquitous in the environment, found in air, water, and soil, at generally

Table 4

Chemical and Physical Characteristics of Contaminants

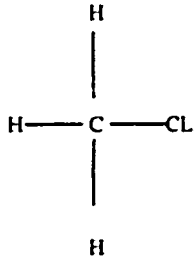
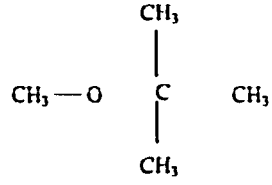
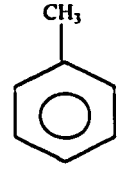
	Benzene	Chloromethane	MTBE	Toluene
Structural Formula				
Molecular Formula	C_6H_6	CH_3Cl	$C_5H_{12}O$	C_7H_8
Molecular Weight	78.11	50.48	88.15	92.14
Melting Point	5.53 °C	-97.1 °C	-109 °C	-95 °C
Boiling Point	80.10 °C	-24.22 °C	55.22 °C	110.6 °C
Density (g/cm^3)	0.8765 at 20/4 °C 0.87378 at 25/4 °C	0.9159 at 20/4 °C	0.74 at 20/4 °C	0.8669 at 20/4 °C 0.86233 at 25/4 °C
Diffusivity in Water (10^5 cm^2/sec)	1.02 at 20 °C 1.09 at 25 °C	1.49 at 25 °C	Miscible in water	0.85 at 20 °C 0.95 at 25 °C
Flash Point	-11 °C	-50 °C	-28 °C	4.5 °C
Lower Explosive Limit (%)	1.2	8.1	1.65	1.1
Upper Explosive Limit (%)	7.8	17.4	8.4	7.1

Table 4 (continued)

Chemical and Physical Characteristics of Contaminants

	Benzene	Chloromethane	MTBE	Toluene
Solubility in Organics	Miscible with: ethanol, ether, glacial acetic acid, acetone, chloroform, carbon tetrachloride, carbon disulfide, oils and hexane	Miscible with: chloroform, ether and glacial acetic acid	Soluble in: alcohol, ether	Soluble in: acetone, carbon disulfide and ligroin; Miscible with: acetic acid, ethanol, ether, benzene, chloroform and other solvents
Solubility in Water at 25 °C	1.800 mg/L	5,350 mg/L	4.8 x 104 mg/L	534.8 mg/L
Octanol/Water Coefficient (K_{ow})	1.3×10^2	0.91	1.24	1.3×10^2
Vapor Density at 25 °C	3.19 g/L 2.70 (Air = 1)	2.06 g/L 1.74 (Air = 1)		3.77 g/L 3.18 (Air = 1)
Vapor Pressure (mm Hg)	60 at 15 °C 76 at 20 °C 118 at 30 °C	3,756 at 20 °C 4,028 at 25 °C 4,962 at 30 °C	245 at 25 °C	22 at 20 °C 28.4 at 25 °C 36.7 at 30 °C
Physical State, Color, and Odor	Rhombic prisms, clear, colorless liquid	Liquified compressed gas, colorless, sweet, ethereal odor	Colorless liquid	Colorless liquid with a pleasant odor similar to benzene.
Henry's Law Constant at 25 °C	5.5×10^{-3} atm-m^3/mol	8.82×10^{-3} atm-m^3/mol	5.87×10^{-4} atm-m^3/mol	5.94×10^{-3} atm-m^3/mol

trace concentrations."

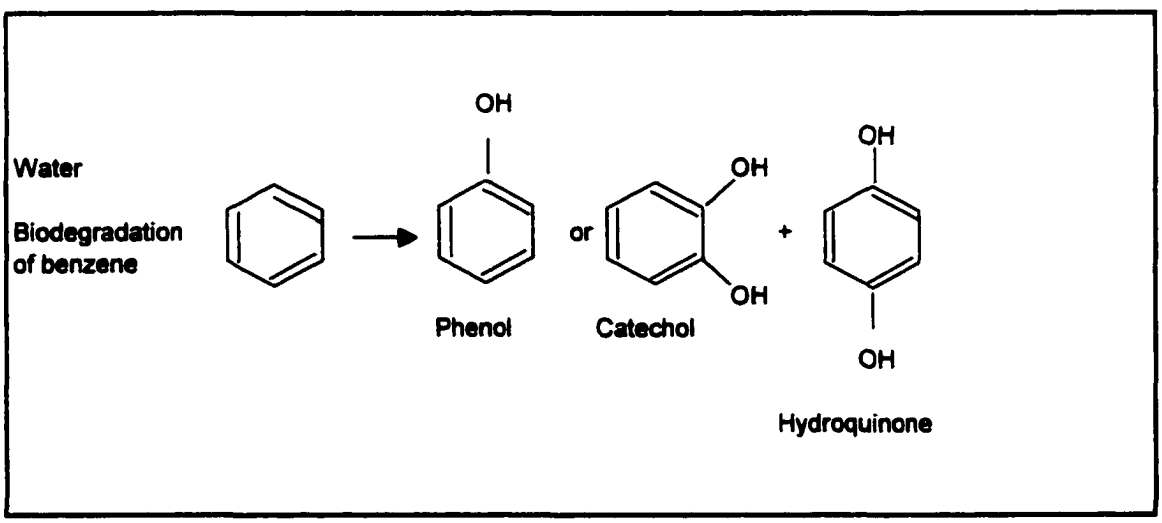
Benzene found in the environment is from both human activities and natural process. "Benzene was first discovered and isolated from coal tar in the 1800s" (ATSDR, 1998a). Today, benzene is made mostly from petroleum sources. "Because of its wide industrial use, benzene ranks in the top 20 in production volume for chemicals in the United States" (ATSDR, 1998a). Various industries use benzene to make other chemicals, such as styrene (for Styrofoam and other plastics), and cychlohexane (for synthetic fibers). "Benzene is also used for the manufacturing of some types or rubbers, lubricant, dyes, detergents, drugs, and pesticides. Natural sources of benzene, which include volcanoes and forest fires, also contribute to its presence in the environment. Benzene is also part of crude oil and gasoline and is even present in cigarette smoke" (ATSDR, 1998a).

Environmental Fate

Biological Degradation

"Microbes have been found to profoundly alter benzene in the environment. A mutant of *Pseudomonas putida* dihydroxylyzed benzene into cis-benzene glycol, accompanied by partial dehydrogenation, yielding catechol" (Dagley, 1972). "Bacterial dioxygenases can cleave catechol at the ortho and metha positions to yield cis,

cis-muconic acid and α-hydroxymuconic semialdehyde, respectively" (Chapman, 1972). "Pure microbial cultures hydroxylated benzene to phenol and two unidentified phenols" (Smith and Rosazza, 1974). "Muconic acid was reported to be the bio-oxidation product of benzene by *Nocardia corallina V-49* using hexadecane as the substrate" (Keck et al., 1981). "In activated sludge, 29.2 % of the benzene converted to carbon dioxide after 5 days" (Freitag et al., 1985). "In anoxic groundwater near Bemidji, Michigan, benzene was anaerobically biodegraded to phenol" (Cozzarelli et al., 1990). "When benzene was statically incubated in the dark at 25 °C with yeast extract and domestic wastewater inoculum, significant biodegradation with rapid adaptation was observed. At concentrations of 5 and 10 mg/L, 49 and 37 % biodegradation, respectively, were observed after 7 days. After 14 days of incubation, benzene demonstrated complete dissimilation" (Tabak et al., 1981). A biodegradation path for benzene is shown in the following box, adapted from ATSDR (1998a):



WHO (1993) has estimated the half life of benzene to be 33 to 384 hours due to aerobic biodegradation in surface waters and 28 to 720 days for anaerobic biodegradation in deep waters and ground water.

Mechanisms of Degradation of Benzene

"The benzene ring is the most widely distributed chemical structure in nature" (ATSDR, 1998a). As a result, "microorganisms have evolved capable of degrading aromatic compounds" (Tabak et al., 1981). As stated by Chiang et al, 1989, "the biodegradation of aromatic compounds can be considered on the one as part of the normal process of the carbon cycle, and on the other as the removal of manmade pollutants from the environment." Considering this situation, I suggest the study site is a place where a normal process of the carbon cycle would take place. This also suggests the biodegradation of benzene at the study site.

"The biodegradation of benzene is primarily *trophic biodeterioration* in which the hydrocarbon is used by the *heterotroph* (an organism that requires food in the form of complex molecules: animals, fungi, and many bacteria) as a carbon and energy source to produce carbon dioxide, water, and biomass" (Hopper, 1978). "In a trophic biodeterioration as benzene is accumulated through the food chain, it is changed or deteriorated from one form to another by the metabolism of various organisms in the food chain. The laboratory results from biological sampling show the presence of carbon

dioxide at the study site, suggesting that benzene might be undergoing trophic biodeterioration. At the study site heterotrophs known to degrade benzene have been identified, suggesting the trophic biodeterioration of this contaminant. Biodegradation of benzene is an aerobic process because hydrocarbons contain no oxygen. Prior to the introduction of the benzene ring, organisms generally are present as a relatively minor component of the total microbial population. After benzene is introduced, the degrader population grows until limitations are imposed by other factors" (Tabak et al., 1981). For example. "The organisms that degrade hydrocarbons most efficiently are aerobes (i.e. use oxygen as the terminal electron acceptor in cellular respiration), oxygen generally becomes the limiting factor. Therefore, an increase in the oxygen content, e.g., subsurface water, increases the population of hydrocarbon degraders, and thus the rate of aromatic hydrocarbon destruction" (Hopper, 1978). At the study site the presence of heterotrophs known to degrade hydrocarbons will speed the biodegradation rate of benzene.

"The successful biodegradation of benzene also depends on the enzymatic capacities of microorganisms and various abiotic factors" (ATSDR, 1998a). These factors include suitable growth temperatures, generally of greater than 15 °C (>59 °F) and available supplies of fixed forms of nitrogen, phosphorus, and molecular oxygen (Taback et al., 1981). The recorded groundwater temperature at the study site has been as high as 25.6 °C (approximately 78 °F). Appendix 6 is a table showing water quality parameters collected during groundwater sampling at the study site. "The minimum nitrate

concentration required to support the optimal growth rate of hydrocarbon degraders ranges between 0.5 and 2.5 mg of nitrate per liter" (Hopper, 1978). At the study site as much as 1.6 mg of nitrate per liter has been found present.

"An analysis of benzene, toluene, and xylene (BTEX) in groundwater from a field site indicated that the amount of BTEX in groundwater was inversely related to the availability of dissolved oxygen. Results of biodegradation experiments in laboratory microcosms using groundwater from the field site showed the following results at BTEX levels of 0.120-16 ppm; BTEX degradation was 80-100% (half-life of 5-20 days) when the dissolved oxygen level was ≥2 ppm; BTEX degradation was slowed (half-life of 20-60 days) when the dissolved oxygen level was <2 ppm; and little or no degradation of BTEX occurred when the dissolved oxygen level was 0, 0.1, or 0.5 ppm" (Chiang et al, 1989). At the study site level of dissolved oxygen as high as 22.3 ppm has been recorded, with an average of approximately 6 ppm throughout the year.

A series of biological samples was also taken at the study site. Unfortunately the laboratory did not analyze for total heterotrophs; therefore, a complete list of the microorganisms at the study site is not available. However, specific heterotrophs, known to biodegrade BTEX, were found. These data support the position that biodegradation of benzene at the study site has occurred. Another set of data that supports the biodegradation of benzene is made of the laboratory results for monitoring Well 4, located approximately 50 feet downgradient from the source. On May 7, 1997 the

concentration of benzene at monitoring Well 4 was 8 ppm. By April 10, 1998 (eleven months later) the concentration of benzene at the same monitoring well was 0.017 ppm. Appendix 7 is a table listing the concentrations of the contaminants at the study site. This represents more than 99.8% reduction, probably produced by biodegradation processes. If we consider the slow mobility of benzene, and that during most of that time interval, gasoline was present at the monitoring wells at the source area, and if we assume that monitoring Well 4 was continuously being contaminated, we could conclude that biodegradation of benzene was nearly 100%.

Another data set that supports biodegradation at the study site consists of the laboratory results for monitoring Well 9. On June 20, 1997 the concentration of benzene at monitoring Well 9 was 0.01 ppm. Follow up laboratory results have shown no hydrocarbon contamination. Monitoring Well 9 might have been contaminated either by creosote from telephone poles around the study site, or by storm water carrying contaminants from a major highway crossing the study area (west bound route 46). As reported by ATSDR, 1998a, the United States Geological Survey (USGS) performed a series of storm water samples in 1996. 6.9 percent (41 of 592) of the samples showed small amount of BTEX and MTBE contamination (ranging from 0.2 ppb in benzene to 0.015 ppm in toluene). The fact that monitoring Well 9 has not shown hydrocarbon contamination since June 20, 1997 suggests that lateral migration at the study site has stopped. Groundwater flow at the study site is toward the west, and monitoring Well 9 is located approximately 200 feet southwest of the source area.

The movement of benzene at the study site has been predicted according to its physical and chemical characteristics, as well as the aquifer characteristics. The study site has been characterized for having an overburden containing clay minerals, which inhibits the movement of benzene.

The groundwater velocity at the study site has been calculated to range between 0.5 and 3 ft/day. If we take the highest calculated value (3 ft/day) and calculate the movement of benzene (with a retardation factor of approximately 1.2) we have: $V^*=V/Rf$, where V^* = the velocity of benzene, V = the velocity of groundwater, and Rf = the retardation factor. $\therefore V^* = 3 ft/day \div 1.2 = 2.5$ ft/day. This calculated velocity does not consider the biodegradation of benzene.

Benzene has been reported to biodegrade both aerobically and anaerobically. "The half-live of benzene has been estimated to be 28 to 720 days for groundwater. The biodegradation of benzene is influenced by several factors, such as microbial population, dissolved oxygen, nitrate concentration, temperature, and pH. Volatilization is another important mechanism in the degradation of benzene" (ATSDR, 1998a).

Other Degradation Mechanisms

"Titanium dioxide suspended in an aqueous solution and irradiated with UV light (λ = 365 nm) converted benzene to carbon dioxide at significant rate" (Mathews, 1986).

"Irradiation of benzene in an aqueous solution yields mucondiadehyde. Photolysis of benzene vapor at 1849-2000 Å yields ethylene (C_2H_4), hydrogen, methane (CH_4), ethane (C_2H_6), toluene and a polymer resembling cuprene" (Montgomery, 1995). "Other photolysis products reported under different conditions include fulvene, acetylene (C_2H_4), substituted trienes, phenol (C_2H_6O), 2-nitrophenol, 4-nitrophenol, 2,4-dinitrophenol, 2,6-dinitrophenol, nitrobenzene, formic acid and peroxyacetyl nitrate" (Calvert and Pitts, 1996). "Under atmospheric conditions, the gas-phase reaction with hydroxyl radicals and nitrogen oxides resulted in the formation of phenol and nitrobenzene" (Atkinson, 1990). "A carbon dioxide yield of 40.8 % was achieved when benzene adsorbed on silica gel was irradiated with light ($\lambda > 290$ nm) for 17 hours" (Montgomery, 1995). These degradation mechanisms could be considered to further treat benzene at the study site.

Kanno et al. (1982) studied the aqueous reaction of benzene and other aromatic hydrocarbons (toluene, xylene and naphthalene) with hypochlorous acid in the presence of ammonium ion. They reported that "the aromatic ring was not chlorinated as expected (forming chlorobenzene) but was cleaved by chloramine forming cyanogen chloride." They also implied that "the amount of cyanogen chloride formed was inversely proportional to the pH of the solution. At pH 6, the greatest amount of cyanogen was formed when the reaction mixture contained ammonium ion and hypochlorous acid at ratio of 2:3." "In the gas phase, benzene reacted with nitrate radicals in purified air forming nitrobenzene" (Chiodini et al., 1993). No data is available at the study site as to corroborate this degradation mechanism for benzene.

"Benzene will not adsorb to bottom sediments because of its soil/organic carbon sorption coefficient which makes it fairly mobile in soil depending on soil type, its high solubility and its volatilization" (WHO, 1993). However, the presence of clay at the study site will inhibit the mobility of benzene, giving the opportunity to microorganisms to degrade it.

Note that at the study site, physical factors such as temperature of water, presence of nitrate, degree of water oxygenation, and presence of microbial biota, speak for rapid benzene degradation.

Chloromethane

Chloromethane is clear and colorless. It has a faint, sweet odor that is noticeable only at levels that are considered toxic. With a molecular weight of 50.49, chloromethane is heavier than air (mw = 28.97 g/mol) and is extremely flammable (ATSDR, 1998b). Chloromethane occurs as a natural compound in the environment; it is found in air at very low levels (0.006-0.009 ppm). "Most of the naturally occurring chloromethane comes from chemical reactions that occur in the oceans or from chemical reactions that occur when material like grass, wood, charcoal, and coal are burned. Approximately 8% of the chloromethane in the environment comes from the production of chlorinated agricultural chemicals (pesticides and fungicides). It is also released to the air as a product of some

plants or from rotting wood" (ATSDR, 1998b). "Most chloromethane discharged into the environment will be released into the air, where it will be subjected to transport and diffusion into the stratosphere" (Singh et al., 1979). "The amount removed from the air through precipitation has not been quantified" (ATSDR, 1998b). However, "the solubility of chloromethane in water indicates that small amounts are removed through the process" (Singh et al., 1982). "The dominant tropospheric removal mechanism for chloromethane is generally thought to be hydrogen abstraction by hydroxyl radicals. In this process the free radical OH grabs a hydrogen from CH_3Cl (chloromethane) to form water (H_2O) and the free radical CH_2Cl ($OH + CH_3Cl \Rightarrow H_2O + CH_2Cl$). The free radical CH_2Cl goes on in a chain reaction to grab another electron from another atmospheric molecule, and then this next molecule missing an electron tries to get one from yet another molecule, and so forth" (ATSDR, 1998b).

Chloromethane is produced industrially. In the past, chloromethane was widely used as a refrigerant, but is no longer used because of its toxicity. "A working refrigerator that is more than 30 years old may still contain chloromethane and might be a source of high-level exposure . It was also used as a foam-blowing agent, as a pesticide and fumigant" (ATSDR, 1998b).

"Today, nearly all commercially produced chloromethane is used to make other substances, mainly silicones (72 % of the total chloromethane used). Other products that are made from reactions involving chloromethane include agricultural chemicals, methyl

cellulose, quaternary amines, and butyl rubber. Chloromethane is completely consumed in most processes so that by the end of each there should be little or no chloromethane remaining" (ATSDR, 1998b). It is, however, found as a pollutant in municipal waste streams from treatment plants and industrial waste streams as a result of chlorination processes. "There are also some manufacturing processes for vinyl chloride that result in chloromethane formation. Chloromethane may be formed to a small extent in tap water that has been chlorinated" (ATSDR, 1998b). Additionally, "chloromethane may be the product of anaerobic metabolism of higher chlorinated methanes occasionally present in the soil" (Vogel et al., 1987).

Chloromethane breaks down very slowly (months to years) in the air. It can dissolve in water, and small amounts of chloromethane in air may enter surface waters or groundwater when it rains. Chloromethane in air has a half-life of about one year (ATSDR, 1998b). At the study site it is thought that a reaction occurred between creosote from telephone and power lines and a chlorinated phenol compound to create methyl chloride. The chlorine have originated from salt used and stored at the study site.

"Small amounts of dissolved chloromethane may move below the surface of the water or be carried to the groundwater. It breaks down very slowly in water, but anaerobic organisms in water are thought to break it down more quickly (days)" (ATSDR, 1998b). "Chloromethane may degrade anaerobically via reductive dechlorination to form methane" (Vogel et al., 1987). "Chloromethane does not tend to concentrate in

sediments, or in animals and fish in the food chain. Most of the chloromethane in soil will become airborne. Some may dissolve in water and move down through the soil layers to the groundwater or into well water" (ATSDR, 1998b).

Environmental Fate

Photolytic

"Reported photooxidation products via hydroxyl radicals include formyl chloride, carbon monoxide (CO), hydrogen chloride and phosgene" (Montgomery, 1995). "In the presence of water, formyl chloride hydrolyzes to hydrochloric acid (HCl) and carbon monoxide, whereas phosgene hydrolyzes to hydrogen chloride and carbon monoxide" (Morrison and Boyd, 1971). No specific studies have been conducted at the study site as to corroborate this processes.

Chemical/Physical

"The estimated hydrolysis half-life in water at 25 °C and pH 7 is 0.93 years" (Mabey and Mill, 1978). "The evaporation half-life of chloromethane (1 mg/L) from water at 25 °C is 27.6 minutes" (Dilling, 1977).

"In water, chloromethane can degrade by hydrolysis or by biodegradation. Although few data were available on the biodegradation of chloromethane in water, neither hydrolysis nor biodegradation in surface waters appears to be rapid when compared with volatilization. The rate constant for hydrolysis of chloromethane at 50 °C (122 °F) was reported to be 7.6 x 10^{-7} sc^{-1}, which yields a half-life of 10.6 days" (ATSDR, 1998b). As reported by ATSDR (1998b), "very little information is available concerning the biodegradation of chloromethane in water." "In studies involving such bacteria as *Methylococcus capsulatus*, formaldehyde was a product of biodegradation" (Stirling and Dalton, 1979). "Chloromethane is degraded by both aerobic and anaerobic bacteria. In both systems the methyl group of chloromethane is transferred by a methyltransferase I onto a protein-bound cobalt (I) atom, from where it is transferred by a methyltransferase II onto methyl-tetrahydrofolate, the first detectable intermediate of the degradative pathway" (Stirling and Dalton, 1979). "In the aerobic system methyl-tetrahydrofolate is subsequently oxidized via methylene-, methenyl-, formyl-tetrahydrofolate to formate and finally to carbon dioxide to form acetate as the final product" (Montgomery, 1995). More laboratory data would be needed to find out the total heterotrophs at the study site in order to predict the environmental fate of chloromethane, if the contaminant is present again in the future at such site.

Chloromethane is thought to be a byproduct reaction, which left no significant contamination at the study area, and has not been detected since June 20, 1997. Chloromethane does not appear to be a significant problem to the study site. The highest

level of chloromethane contamination at the study site was 0.18 ppm at monitoring Well 2 on March 21, 1997 and on June 12, 1997 (0.18 ppm on both dates).

Toluene

Toluene, a methylated benzene ring, is a clear, colorless liquid with a sweet smell, at ambient temperature. A person may begin to smell toluene in the air at a concentration of 8 ppm, and taste it in water at a concentration of 0.04 to 1 ppm (ATSDR, 1998c). Toluene occurs naturally in crude oil, coal tars, and the tolu tree. Tolu is a tall tree native of northern South America, found predominantly in Colombia, Peru and Venezuela. It is also found in some areas of Argentina, Paraguay, and Bolivia. Toluene is produced in the process of making gasoline (approximately 5 to 7% toluene remains in gasoline) and other fuels from crude oil, in making coke from coal, and as a byproduct in the manufacture of styrene. Toluene is used in making paints, lacquers, adhesives, rubber, paint thinners, and in some printing and leather processes.

Toluene enters surface water and groundwater from spills of petroleum products and leaking underground storage tanks. Toluene dissolved in groundwater does not break down quickly, but once the water is brought to the surface, the toluene will evaporate into the air. Toluene can be taken up by fish and shellfish, plants and by higher life forms in contaminated water. However, it does not concentrate to high levels (>90 Mg/L)

(ATSDR, 1998c). "Despite its lipid solubility, the bioconcentration factor for toluene is relatively low due to its rapid metabolism to more polar molecules with a lower affinity for lipids; it has little tendency to bind to biomolecules. Toluene is sequestered in lipid-rich (fatty), highly vascular (many blood vessels) tissues. The brain is one such site" (ATSDR, 1998c).

Environmental Fate

Biological

"Toluene can undergo two types of microbial attack. The first type proceeds via immediate hydroxylation of the benzene ring. The second type of attack proceeds via oxidation of the methyl group followed by hydroxylation and ring cleavage" (Montgomery, 1995). "A mutant of *Pseudomonas putida* oxidized toluene to (+)-cis-2, 3 dihydroxy-1-methylcyclohexa-1,4-diene" (Dagley, 1972). Claus and Walker (1964) reported that "*Pseudomonas sp.* and an *Achromobacter sp.* oxidized toluene to 3-methyl catechol." "Other metabolites identified in the microbial degradation of toluene include cis-2,3-dihydroxy-2,3-dihydrotoluene, 3 methyl catechol, benzyl alcohol (C_7H_8O), benzaldehyde (C_6H_5CHO), benzoic acid ($C_7H_6O_2$), catechol and 1-hydroxy-2-naphthoic acid" (Montgomery, 1995). "In a methanogenic aquifer material, toluene degraded completely to carbon dioxide" (Wilson et al., 1983). "In activated sludge, 26.3 % of the toluene degraded to carbon dioxide after 5 days" (Freitag et al., 1985).

"In anoxic groundwater near Bemidji, Michigan, toluene anaerobically biodegraded to the intermediate benzoic acid" (Cozzarelli et al., 1990). "Methylmuconic acid was reported to be the biooxidation product of toluene by *Nocardia corallina V-49* using n-hexadecane as the substrate. With methane as the substrate and *Methylosinus trichosporium OB3b* as the microorganism, p-hydroxytoluene and benzoic acid are the product of biooxidation" (Montgomery, 1995). In addition, "*Methyloccus capsulatus* was reported to bioxidize toluene to benzyl alcohol and cresol. When toluene (5 and 10 mg/L) was statically incubated in the dark at 25 °C with yeast extract and domestic wastewater inoculum for 7 days, 100 % biodegradation with rapid adaptation was observed" (Keck et al., 1981). "Pure microbial cultures isolated from soil hydroxylated toluene to 2- and 4-hydroxytoluene" (Smith and Rosazza, 1974). "When toluene (5 and 10 mg/L) was statically incubated in the dark at 25 °C with yeast extract and domestic wastewater inoculum for 7 days, complete biodegradation with rapid acclimation was observed, obtaining similar results as Keck et al (1981)" (Montgomery, 1995).

Photolytic

"A n-hexane solution containing toluene and spread as a thin film (4 mm) on cold water (10 °C) was irradiated by a mercury medium pressure lamp. In 3 hours, 26 % of the toluene photooxidized into benzaldehyde, benzyl alcohol, benzoic acid and m-cresol" (Moza and Feicht, 1989). "Methane and ethane were reported as products of the gas-phase photolysis of toluene at 2537 Å" (Calvert and Pitts, 1966). No detailed studies

have been done at the study site to well understand the photolytic degradation characteristics of toluene.

Montgomery (1995) reported that "irradiation of toluene (80 ppm) by UV light (λ = 200-300 nm) on titanium dioxide in the presence of oxygen (20%) and moisture resulted in the formation of benzaldehyde and carbon dioxide. Carbon dioxide concentrations increased linearly with the increase in relative humidity. However, the concentration of benzaldehyde decreased with an increase in relative humidity."

"Irradiation of toluene in the presence of chloride yielded benzyl hydroperoxide, benzaldehyde, peroxybenzoic acid, carbon monoxide, carbon dioxide and other unidentified products. The photooxidation of toluene in the presence of nitrogen oxides (NO and NO_2) yielded small amounts of formaldehyde and traces of acetaldehyde or other low molecular weight carbonyls" (Freitag et al., 1985). Other photooxidation products not previously mentioned include phenol, phthalaldehydes and benzol alcohol (Freitag et al., 1985). "A carbon dioxide yield of 8.4 % was achieved when toluene adsorbed on silica gel was irradiated with light (λ > 290 nm) for 17 hours" (Freitag et al., 1985). This process has not been found relevant to the study site at the present time.

Chemical/Physical

"Products identified from the reaction of toluene with nitric oxide and hydroxyl radicals include benzaldehyde, benzyl alcohol, m-nitro-toluene, p-methylbenzoquinone, o-, m-andp-cresol. Gaseous toluene reacted with nitrate radicals in purified air forming the following products: Benzaldehyde, benzyl alcohol, benzyl nitrate, 2-, 3- and 4-nitrotoluene" (Kenley et al., 1978).

"Under atmospheric conditions, the gas-phase reaction with hydroxyl radicals and nitrogen oxides resulted in the formation of benzaldehyde, benzyl nitrate, m-nitrotoluene, 0-, m- and p-cresol" (Montgomery, 1995).

Kanno et al. (1982) studied the aqueous reaction of toluene and other aromatic hydrocarbons (benzene, o-, m- and p-xylene and naphthalene) with hypochlorous acid in the presence of ammonium ion. They stated that "although chlorination of the aromatic was observed with the formation of 2- and 4- chlorotoluene, the major degradative pathway was cleavage of the aromatic ring by chloramine, forming cyanogen chloride." The amount of cyanogen chloride formed was inversely proportional to the pH of the solution. At pH 6, the greatest amount of cyanogen chloride was formed when the reaction mixture contained ammonium ion and hypochlorous acid at a ratio of 2:3 (Kanno et al., 1982).

Although toluene is a liquid at room temperature, it is sufficiently volatile that the majority of toluene released to the environment partitions into the atmosphere. "Toluene in the atmosphere is rapidly degraded by reaction with hydroxyl radicals to yield cresol and benzaldehyde, which in turn undergo ring cleavage to yield simple hydrocarbons" (Davis et al., 1979). "Although toluene may be oxidized in water by reactions similar to those that occur in air, the rates of these reactions in water are much slower" (Callahan et al., 1979). "Degradation of toluene in water occurs primarily by microbial action." (Montgomery, 1995). "The rate of biodegradation is a function of many parameters (temperature, groundwater elevation, duration of microbial acclimation, etc.), with half-lives less than 1 day under favorable conditions" (Wakeham et al., 1983). "Rapid biodegradation (over 90 % loss within 7 days) also occurs in shallow groundwater" (Wilson et al., 1983) and in sludge waste water (Davis et al., 1981). The study site has shown a water table as shallow as 1 foot below ground surface (following a storm), suggesting a favorable condition for the biodegradation of toluene. "Reduced but still considerable, rates of toluene microbial degradation were reported in salt water, as compared to fresh water" (Price et al., 1974).

"Toluene can be degraded in soil by a number of bacterial species of the geneus *Pseudomonas* and *Achromobacter*" (Fewson, 1981). "The biodegradation process appears to occur in two phases. The first phase produces benzoic acid and is, in this respect, parallel to the metabolism of toluene by mammalian microsomes. In the second phase, the aromatic ring undergoes metabolic cleavage to produce intermediates of the

Krebs cycle (the citric acid cycle) which are degraded to carbon dioxide, or incorporated into bacterial biomolecules" (Harayama et al., 1989). "In aerobic soils, oxygen acts as the terminal electron acceptor in degradation of the ring cleavage products. Under anaerobic conditions, nitrogen can act as the terminal electron acceptor with the reduction of nitrate to nitrite" (Dolfing et al., 1990). "The half-life for biodegradation in soil under laboratory conditions may be as short as 1 hour" (Claus and Walker, 1964), whereas "half-lives of 1-7 days are typical conditions in the environment" (ERT, 1984). "Soil biodegradation is not impeded by adsorption" (Robinson et al., 1990). As already mentioned, it is known that organisms capable of degrading hydrocarbons are present at the study site. However, no specific organisms have been identified. A more detailed laboratory study is necessary for this matter.

Toluene can undergo both aerobic and anaerobic degradation. Aerobic bacteria use molecular oxygen as a substrate for oxidizing toluene. An aerobic degradation of toluene is as follows: Toluene + xylene monooxygenase → benzyl alcohol. An anaerobic pathway for toluene has the following reaction: Toluene + fumarate → Benzylsuccinate.

Methyl Tertiary Butyl Ether (MTBE)

"Methyl tertiary butyl ether (MTBE) is a chemical added to gasoline to promote

more complete combustion and reduce emissions of carbon monoxide (CO) and organic compounds" (Lyman et al., 1982). More information about the physical and chemical characteristics of MTBE are available in table 2. "The chemical adds oxygen to the gasoline, which increases the temperature at which it burns in the engines and reduces the amount of harmful byproducts in the vehicle's exhaust" (Sax and Lewis, 1987). The heat content of a fuel (usually expressed in BTUs/gal) is directly related to its density. A typical gasoline would have a value of 120,000 BTUs/gallon. Gasoline mixed with MTBE would have a value of approximately 93,500 BTUs/gallon.

"MTBE has a distinctive odor that most people find disagreeable" (ATSDR, 1998d). It was first introduced in the 1980s to enhance octane ratings in gasoline and to reduce automotive smogs. In city areas where there are concerns over pollutants carbon monoxide, the EPA has also required the use of MTBE, or ethanol, as an oxygenating agent to make the fuel burn more cleanly during the winter months. Fuels containing these additives are called reformulated gasolines. "The EPA says that MTBE reduces CO by 20%, but a recent review by government scientists indicates that CO is reduced by only 5-10%" (Joseph, 1997). Most MTBE is mixed with gasoline, so most people would come in contact with it while exposed to automobile fuel vapors or exhausts. "MTBE has other special uses as a laboratory chemical and in medicine to dissolve gallstones" (ATSDR, 1998d).

"The total annual industrial emissions of MTBE in the United States in 1992, as

reported on the Toxic Release Inventory, were an estimate of 3 million pounds: 2.8 million pounds to air, 100 thousand pounds to surface water, 68 thousand pounds to underground injection sites, and 288 pounds to land" (Montgomery, 1995).

"MTBE will quickly evaporate from open containers. In the open air, it will quickly break down into other chemical compounds, with half of it disappearing in about 4 hours. Like most ethers and alcohols, MTBE dissolves readily in water. If MTBE is spilled on the ground, rain water can dissolve it and carry it through the soil via groundwater. Spill or leaks from storage containers can seep into deeper soil layers and thereby pollute groundwater, especially near manufacturing sites, pipelines, and shipping facilities" (ATSDR, 1998d). Leakage from underground storage tanks, such as at gasoline filling stations, can also add MTBE to groundwater. "Because of its high volatility in surface water (half-life in streams, rivers, and lakes estimated to be 2.5 hours, 9.5 hours, and 3,296 hours (137 days) respectively), MTBE has not been shown to concentrate in either fauna or flora in lakes, ponds, and rivers" (ATSDR, 1998d).

Environmental Fate

Chemical/Physical

"MTBE is a relative volatile chemical and is moderately soluble in water. It is very soluble in some organic solvents such as alcohol and ether" (ATSDR, 1998d). "MTBE is flammable, and is a moderate fire risk" (Sax and Lewis, 1987).

Because it mixes readily with gasoline, is easily transported, has a low production cost and high (110) octane rating (fuels are rated according to their ability to burn smoothly and avoid engine valve "knocking" -this rating is called the octane rating-). "MTBE has become the oxygenate of choice for most gasoline producers who face state and federal mandates to produce less-polluting gasoline" (MacKay et at., 1993). "Although MTBE is readily mixed with gasoline, it does not appear to be easily absorbed by soil" (Lyman et al., 1982). As a result, the MTBE moves from the leaking gasoline source into the water where it is dissolved. MTBE is hydrophilic.

"MTBE undergoes degradation once released into the atmosphere through reaction with hydroxyl radicals. Based on equilibrium fugacity models, the high vapor pressure of MTBE leads to partitioning to the atmosphere for MTBE releases to surface waters or soil surfaces" (MacKay et al., 1993). In model systems, half-lives (first-order kinetics) in moving water are estimated to be 4.1 hours (HSDB 1995, noting estimates

based on a method presented by Lyman et al., 1982).

MTBE is not expected to hydrolyze, photolyze, or be adsorbed to sediments or suspended particulate matter (Montgomery, 1995). MTBE has been reported to degrade into a chemical called tertiary butyl formate (TBF) which is a "highly and acutely toxic" (Joseph, 1997). However, MTBE is thought not to represent a problem at the study site since its ultimate transportation fate is expected to be the Musconetcong river. At that point MTBE is expected to partitioning to the atmosphere.

Toxicity

Benzene

"Benzene toxicity involves both bone marrow depression and leukemogenesis caused by damage to multiple classes of hematopoietic cells and a variety of hematopoietic cell functions. It affects white cells and causes leukemia" (ATSDR, 1998a). "Benzene toxicity to humans exposed in the workplace has been characterized as either early reversible hematotoxicity or, with prolonged exposure to high doses, irreversible bone marrow damage" (Snyder & Hedli, 1996).

Symptoms of Exposure-Acute and high level of exposure

The methods of entry of benzene into the human body are via the lungs, through the skin, and might be ingested through food, beverages, or drinking water (Budavari et al., 1989). "Some of the symptoms are: irritation of mucous membranes, restlessness, excitement, and depression" (ATSDR, 1998a). "Other symptoms include: hallucination, distorted perception, euphoria, somnolence, nausea, vomiting and headache. The effects are narcotic at air concentrations of 200 ppm. At higher concentrations, convulsions may occur. Eye, nose and respiratory irritant" (Patnaik, 1992).

Chloromethane

Chloromethane can enter the human body through the lungs, or through the digestive tract (ATSDR, 1998b). Inhaled rapidly enters the bloodstream, and move throughout the host. The target organs are the liver, kidneys, and brain (ATSDR, 1998b). If the levels are high enough (over a million times the natural levels (0.6-0.9 ppb) in outside air), even brief exposures to chloromethane can have serious effects on the nervous system, including convulsions, coma, and death (ATSDR, 1998b). This is not thought to be a concern at the study site due to the low concentration of chloromethane, where the concentrations have not been detected to be more than 0.03 ppm.

Chloromethane can enter the human body by inhalation or ingestion. Chloromethane is also thought capable of entering a host on skin contact, but the amount that may enter percutaneously is unknown (ATSDR, 1998b). However, as previously stated, chloromethane is believed not to represent a problem at the study site. The data obtained from the study site should be a legitimal argument for the New Jersey Department of Health to inform the local population that chloromethane is of not hazard to them. The compound "exhibits toxic properties: acute (short-term) exposure to high concentrations of chloromethane in humans has caused neurological effects including convulsions, coma, and even death" (Baird, 1954). Chloromethane has also caused cardiac and blood pressure effects, liver, and kidney damage (McKenna et al., 1981).

Chronic: No human data were available regarding the chronic (long-term) effects associated with low level exposure of chloromethane. However, "chronic exposures to animals have shown lesions produced in the liver, kidney, spleen and brain of mice; and, lesions in the testes of rats and mice" (Makie, 1961). "Delayed fetal development was found in rats exposed to the same concentration of chloromethane that resulted in maternal toxicity" (McKenna et al., 1981). Inhalation studies have demonstrated that chloromethane causes reproductive effects in male rats, a consequence of testicular lesions (Hutch et al., 1982). "Animal studies have also found tumors in the liver of male mice" (Makie, 1961).

"The EPA notes only one human epidemiological study" (ATSDR, 1998b). This study did not show any increases in the incidences of cancer in workers exposed to chloromethane. "Inhalation of vapors may cause headache, dizziness, drowsiness, nausea, vomiting, convulsions, and respiratory failure" (Patnaik, 1992). EPA (1996a) has classified chloromethane as a Group C carcinogen, i.e., a "possible human carcinogen, of low carcinogenic potential."

Toluene

A public health concern is that toluene may have effect brain function. "Toluene can cause headaches, confusion, and memory loss" (ATSDR, 1998c). The action of

toluene depends on dose and time (cumulative dose). Low to moderate (80-200 ppm), day-after-day exposure in the workplace can cause tiredness, confusion, weakness, drunken-type actions, memory loss, nausea, and loss of appetite (ATSDR, 1998c). These symptoms usually disappear when exposure ceases. Researchers do not know if low level (<80 ppm) exposure to toluene causes any permanent effects on the brain or other organs.

Several studies have shown that animal fetuses were harmed when high levels (3,000 ppm) of toluene were inhaled during pregnancy (ATSDR, 1998c). However, when the mothers were fed high levels of toluene, the unborn animals did not show any birth defects. It is not known if toluene would harm unborn humans if the mothers drank water or breathed air containing toluene, because such studies have never been undertaken. This type of exposure is unlikely to occur at the study site.

Studies of workers, and animals, exposed to toluene indicate that toluene is not carcinogenic. The International Agency for Research on Cancer (IARC) and the Department of Health and Human Services (DHHS) have not classified toluene for carcinogenic effects (ATSDR, 1998c). The EPA (1980) has determined that toluene is not classifiable as to it human carcinogenicity.

Symptoms of Exposure

"May cause headache, dizziness, excitement, euphoria, hallucination, distorted percuptious and confusion. Narcotic at high concentrations" (Patnaik, 1992).

MTBE

"MTBE caused side effects in some patients who were given MTBE to dissolve gallstones" (ATSDR, 1998d). The MTBE is given to these patients through special tubes (the technique is called laparascopic cholecystectomy) that are placed into their gallbladders. MTBE is not ingested, but it is used as a local irrigation. It remains a liquid at body temperature, and it is said to work in just a few hours. "If MTBE leaks from the gallbladder into other areas of the body, the patient can have minor liver damage, a lowering of the amount of white blood cells, nausea, vomiting, sleepiness, dizziness, and confusion. These effects are not long-lasting . Another problem that arises might be the diseased gallbladder, and stones may recur" (ATSDR, 1998d). No data were located by the United States Department of Health or any other researcher regarding death in humans following any type of exposure to MTBE (ATSDR, 1998d).

The most common effect of MTBE in animals is on their nervous system. Breathing MTBE at high levels can cause animals to acts as if they are inebriated

(ATSDR, 1998d). "When rats breathed high levels of MTBE for several hours every day for two years, some experienced more serious kidney disease than these rats usually get as they grow old" (ATSDR, 1998d). Some of the males rats developed cancer in the kidney, but whether this effect may be extrapolated to humans is unknown. "When mice breathed high levels of MTBE for several hours every day for a year and a half, some had larger livers than normal; some mice developed tumors in the liver" (ATSDR, 1998d). When rats were given high levels of MTBE, orally, for 2 years, some male rats developed cancer of testes and some female rats developed cancer of the blood (leukemia) and soft tissues (lymphoma) (ATSDR, 1998d). "When pregnant rats, rabbits, or mice breathed MTBE, birth defects occurred only in the mice offspring" (ATSDR, 1998d). Again, the relevance of these findings for humans is unknown. Such exposures at the study sites are not likely to occur.

Symptoms of exposure

"Persons exposed to MTBE pumping gasoline, driving cars, or working as attendants or mechanics at gas stations, complain of headaches, nausea, dizziness, irritation of the nose or throat, and feelings of confusion" (ATSDR, 1998d). These symptoms were reported when high levels of MTBE (more than 15 %) were added to gasoline. "MTBE has a very unpleasant odor that most people can smell before any harmful effects would occur, but some people might feel irritation of the nose or throat before noticing the smell" (ATSDR, 1998d). "Respiratory symptoms are due to irritation

of the tissues in lungs, bronchial tubes, and nasal passages" (Joseph, 1997).

Regulations

Benzene

In 1974, Congress passed the Safe Drinking Water Act. This law requires the Environmental Protection Agency (EPA) to determine safe levels of chemicals in drinking water which do or may cause health problems. These non-enforceable levels, based solely on possible health risks and exposure, are called Maximum Contaminant Level Goals (MCLG). The MCLG for benzene has been set at zero (EPA, 1991). Based on this MCLG, EPA has set an enforceable standard called a Maximum Contaminant Level (MCL). The MCL has been set at 0.005 parts per million (ppm) by the EPA. The New Jersey Department of Environmental Protection (NJDEP) has set a "Ground Water Quality Criteria" of 0.001 ppm for benzene.

The International Agency for Cancer Research (IARC) classifies benzene as a Group 1 carcinogen (carcinogenic to humans) (IARC 1987). The EPA assigns Class A (human carcinogen) (Integrated Risk Information System -IRIS, 1996-), and the National Toxicology Programs (ATSDR, 1998a) lists benzene as a "substance known to be carcinogenic," that is, a substance for which the evidence from human studies indicates that there is a causal relationship between exposure to the substance and appearance of excess human cancer . Benzene is also on the list of chemicals in "The Emergency Planning and Community Right-to-Know Act of 1986" (EPA, 1988a).

Benzene is regulated by the Clean Water Effluent Guidelines in 40 CFR Part 401. For each point source category, benzene may be regulated as part of a group of chemicals controlled as total toxic organics, may have a specific regulatory limitation, or may have a zero discharge limitation. The point source categories for which benzene is controlled as a total toxic organic includes electroplating (EPA, 1981), metal finishing (EPA, 1983a), metal molding and casting (EPA, 1985), and copper forming (EPA, 1983b). The point source categories for which benzene has a specific regulatory limitation include organic chemicals (EPA, 1993), and iron and steel manufacturing (EPA, 1982).

Chloromethane

The Occupational Safety and Health Administration (OSHA, 1974) issues permissible exposure limits for chloromethane of 100 parts per million (ppm), over an 8-hour time-weighted average for the work day. Further, a 200 ppm acceptable ceiling concentration may occur during the work day; and, 300 ppm, acceptable maximum peak above ceiling for the eight-hour shift, for a maximum period of 5 minutes within any 3-hour period.

The EPA Offices of Air and Radiation, Drinking Water, Emergency and Remedial Response, Solid Waste, and Prevention, Pesticides, and Toxic Substances also regulates chloromethane. Chloromethane is cited as a regulated compound under the Emergency

Planning and Community Right-to-Know Act; Clean Air Act; Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Clean Water Act, on the Priority Pollutant List; and Resources Conservation and Recovery Act. Under the Emergency planning and Community Right-to-Know Act, releases of more than one pound of chloromethane into the air, water, or land annually must be reported and entered into the national Toxic Release Inventory (TRI, 1996).

The EPA has not assigned a carcinogenity classification for chloromethane (IRIS, 1996). Health advisories published by the EPA Office of Water assign chloromethane to cancer group C, which indicates that the substance is a possible human carcinogen (EPA, 1996). The International Agency for Research on Cancer (IARC) has classified chloromethane as Group 3; not classifiable as to its carcinogenicity to humans (IARC, 1987). The National Toxicology Program (NTP) has not classified the chemical for carcinogenicity. The National Institute for Occupational Safety and Health (NIOSH) recommends that chloromethane be treated as a potential occupational carcinogen (NIOSH, 1992). The NJDEP has set a "Ground Water Quality Criteria" of 0.03 ppm for chloromethane.

Toluene

The Occupational Safety and Health Administration (OSHA) has set a limit of

200 ppm of toluene for air in the workplace, averaged for an 8-hours exposure per day over a 40-hour work week. The American Conference of Governmental Industrial Hygienists (ACGIH) and the National Institute for Occupational Safety and Health (NIOSH) have recommended that toluene in the workplace not exceed 100 ppm (as an average level over 8 hours). The EPA has recommended that drinking water should not contain more than 21.5 ppm for 1 day or 2 ppm for 10 days of consumption. The NJDEP has set a "Ground Water Quality Criteria" of 1 ppm for toluene. Compared with the 200 ppm (200,000 ppb) limit set by OSHA on toluene, the 1 ppm (0.001 ppb) level set by NJDEP seems to be very stringent. Apparently states regulations are directly affected by local politics. We can clearly see this situation when we compare the drinking water quality standards in Vermont (2,420 ug/L) (ATSDR, 1998c) with the standards in California (100 ug/L) (ATSDR, 1998c).

The International Agency for Research on Cancer (IARC) and the Department of Health and Human Services (DHHS) have not classified toluene for carcinogenic effects. The EPA has determined that toluene is not classifiable as to its human carcinogenicity.

MTBE

The U.S. Environmental Protection Agency has recently proposed a "health advisory" level for MTBE in drinking water of 0.070 parts per million. This action level

is an advisory indicator level that, if exceeded, triggers the water supplier to notify customers of the presence of MTBE in the drinking water. Currently, there is no regulatory maximum contaminant level for MTBE in drinking water. The Department of Health and Human Services is working with other state and federal government agencies to monitor MTBE levels in drinking water and evaluate the best way to prevent any possible health consequences for the water consumer. The New Jersey Department of Environmental Protection (NJDEP) has also set a "Ground Water Quality Criteria" of 0.070 ppm for MTBE (appendix 9). The EPA is also considering regulating MTBE under the Safe Drinking Water Act.

The Department of Health and Human Services, the International Agency for Research on Cancer (IARC), and the EPA have not classified MTBE for its ability to cause cancer. The EPA has identified MTBE as a possible human carcinogen, Class C (EPA, 1995a), although sufficient data do not support MTBE as carcinogenic. The National Toxicology Program does not have a cancer classification for MTBE.

MTBE is on the list of the chemicals regulated based on "The Emergency Planning and Community Right-to-Know Act of 1986" (EPCRA) (EPA, 1988b). Section 313 of Title III of EPCRA requires owners and operators of certain facilities, such as gas stations and gas facilities, that manufacture, import, or otherwise use the chemicals on the list, to annually report release of those chemicals into any environmental media.

On November 30, 1998, Carol M. Browner, EPA Administrator, appointed a Blue Ribbon Panel of leading experts to investigate concerns raised by the discovery of MTBE in some water supplies. The panel consisted of experts on air and water quality, and also representatives of the oil, ethanol, and MTBE industry and the environmental community. The panel recommended a comprehensive set of improvements of the nation's water protection programs. On July, 1999, the panel agreed broadly that the use of MTBE should be reduced substantially as soon as possible (with some members supporting its complete phase out). The panel chose to rely on recent reports by a number of state, national, and international health agencies.

DISCUSSION

As previously discussed, the study site is located in an area of aquifer recharge, where groundwater flow in the bedrock is controlled by fracture orientation and spacing. Core samples show that fractures decrease with depth, and do not show a preferred orientation, ranging from horizontal to vertical, with spacing ranging from 0.25 to 6 inches. The groundwater flow at the study site is known to be westerly. The former UST was located on the slope at approximately 710 feet above mean sea level.

Also, the soil at the study site consists of mostly grains of medium to fine sand with some silty clay. The rise and fall of the water table has been very important in terms of the contaminants' entrapment in soil at the study site. MTBE is the only contaminant discussed in this thesis that has been detected downgradient of the groundwater treatment system. However, its low concentration (a maximum of 0.67 ppm) is indicative of no hazard at the study site.

The model used to predict the movement of the contaminants was useful. However, it predicted benzene at approximately 1,400 feet, being off by a factor of 7. A monitoring Well between MW 6 and MW 10 would be the only mean to measure a more precise factor. The evaluation of the model suggests that it is not conclusive, and one can not solely rely on models to predict the movement of contaminants, at least on sites with the characteristics of the one presented in this study area.

Both state and government regulations were previously discussed. Such regulations have been implemented to protect the population. However, in some instances they appear to be too stringent.

Some variabilities are found on replicates taken from some wells at the study site. Other variabilities show differences in groundwater parameters taken at the study site. While human errors as previously described might account for some of these variabilities, such variations might be due to natural phenomena. A difference in groundwater parameters taken from wells close together might be due to the fact that a portion of the plume might be influenced by a biological transformation process at a greater rate than neighboring wells. Other natural phenomena include the following: 1) oxygen frequently declines in groundwater because the source of oxygen is at the top of the aquifer. This might account for the difference in dissolved oxygen among monitoring wells at the study site; 2) wells may be intersecting groundwater with different chemistries.

CONCLUSIONS

The concentrations of MTBE at monitoring Wells 10, 11 and 12 are below the "Groundwater Quality Criteria" set by the New Jersey Department of Environmental Protection, and do not represent a hazard at the study site. In the event that MTBE travels past the study site, once it reaches the Musconetcong River it will volatilize very rapidly. This short contamination half-life further decreases its importance as a potential health hazard.

Benzene and toluene biodegraded very rapidly at the study site. They do not represent a health hazard at such site.

A portion of the contamination compounds at the study site may have come from the employee's parking lot (from vehicles), from the onsite truck maintenance garage, from the creosote on telephone poles (Gargiulo, unpublished Ph.D. thesis, 2000), or from surface runoff from a nearby highway (west bound route 46).

After considering all the geological conditions, as well as the contaminant's behavior in groundwater, it is concluded that before a cleanup of a leaking underground storage tank (UST) is initiated, a geological-hydrological site assessment should be undertaken. Many USTs might not need further intervention, since natural attenuation might be an effective method for cleanup. Such sites may be left unabated without

endangering human health or the environment. At other sites cleanup might be effective by introducing microbes into the groundwater. Biological samples should be taken to identify specific microbes at such sites. This will facilitate the decision making in terms of remediation. Research on previous UST leaks would be helpful in evaluating specific sites.

There will be many areas in the United States in which USTs have leached in areas where little data exist concerning soil profile or groundwater movement. In these instances reasonable assumptions could be helpful for preliminary evaluation of hazards.

Appendix 1

Appendix 1

FILE Hackettstown [illegible] Project
SUBJECT
SHEET 1 OF

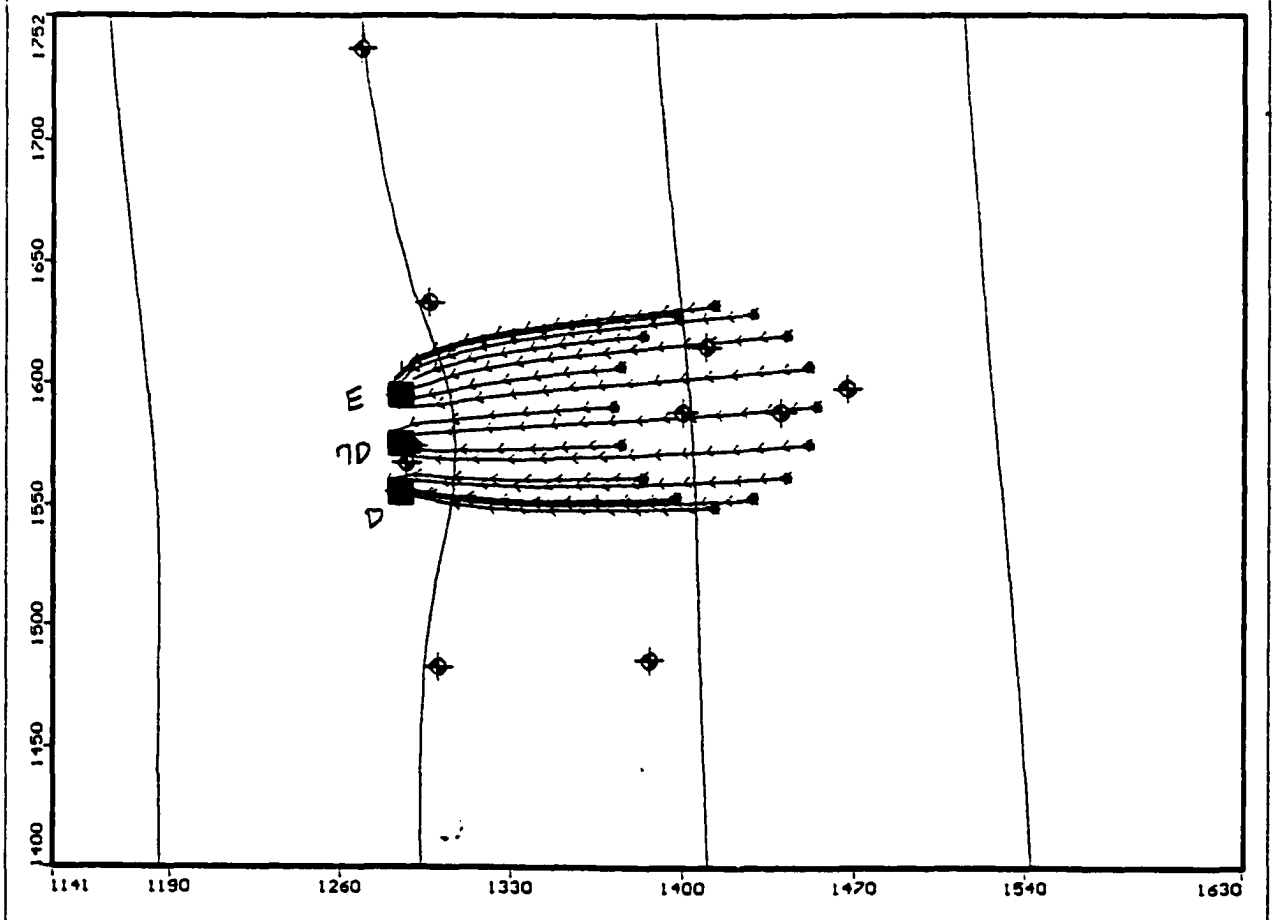
Third Set of Runs on Visual Modflow 8/6/97 – 8/7/97

1. Rotated the grid 29.5° (25) clockwise on its 0,0 origin, then shifted grid 'west' 520 ft.
2. Scaled of gd. surface topo points from USGS topo for new shifted grid
3. Corrected pumping & obs well coordinates as shown on attached table
4. Const Head Boundaries – following calibration to S.S. static water levels:
   Easternmost column ranged from 778' Elev at North end to 720' on south
   Westernmost column ranged from 643' on north to 542' on south
5. Parameters Used:
   K = 1.5 ft/day from distance in x direction from 1100 to 2[illegible]
   K = 6.0 " " " " " " 0 to 110[illegible]
   m = 75 – 100'
   $S_s = 1.25 \times 10^{-6}$ ft^{-1}
   S_y = 0.12
   n = 0.15
   Recharge = 0.5"/yr everywhere
6. Runs at steady state.
   To capture the particles [illegible] to eliminate [illegible] 'C' & replace it with Well 'E' located ~20' north of HW-7D, and then [illegible] capture took place only when HW-7D + Well 'C' were each pumping at 2.5 gpm, and Well 'E' was pumping at [illegible] gpm

A. Mullins DATE 8/7/97
CHECKED BY
[illegible] TO EO

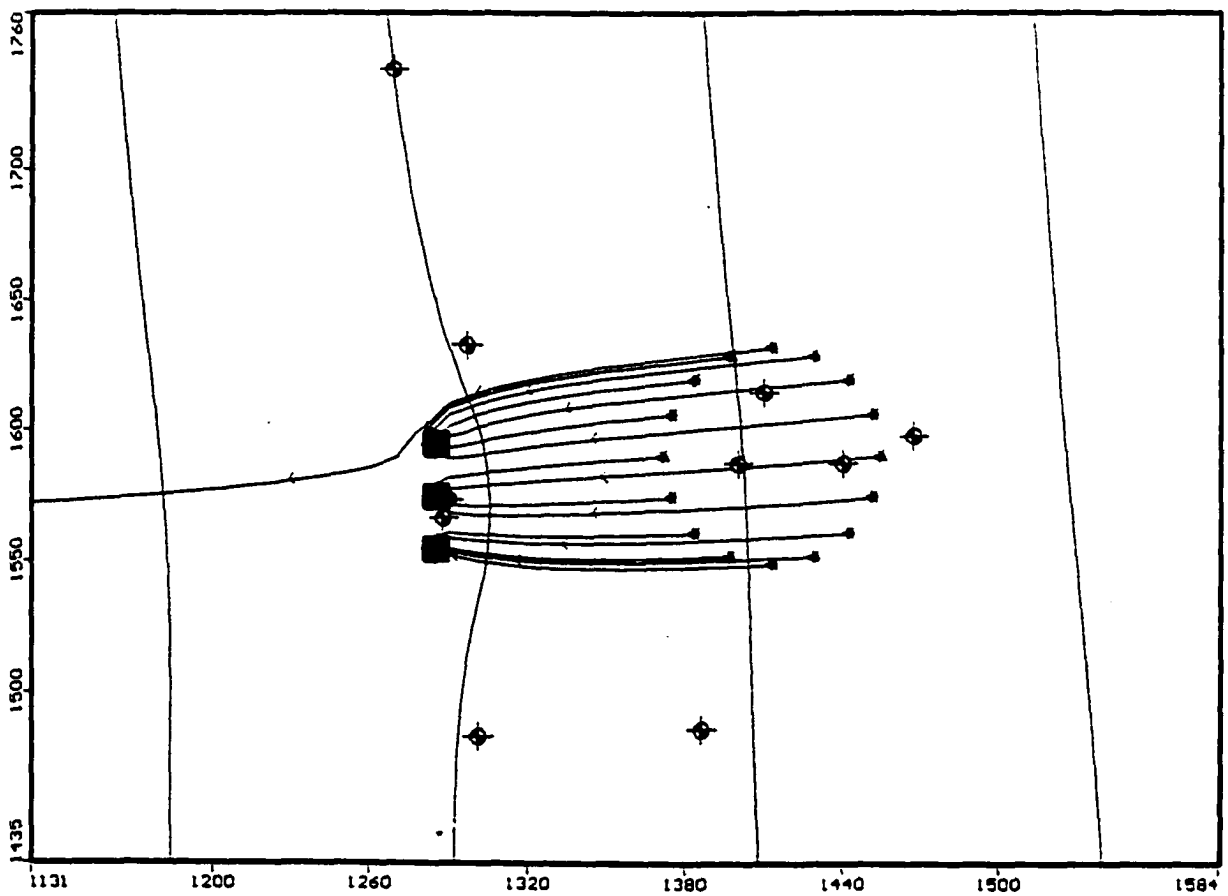
REVISIONS
BY ____ DATE ____ TO EO ____
BY ____ DATE ____ TO EO ____

Dames & Moore



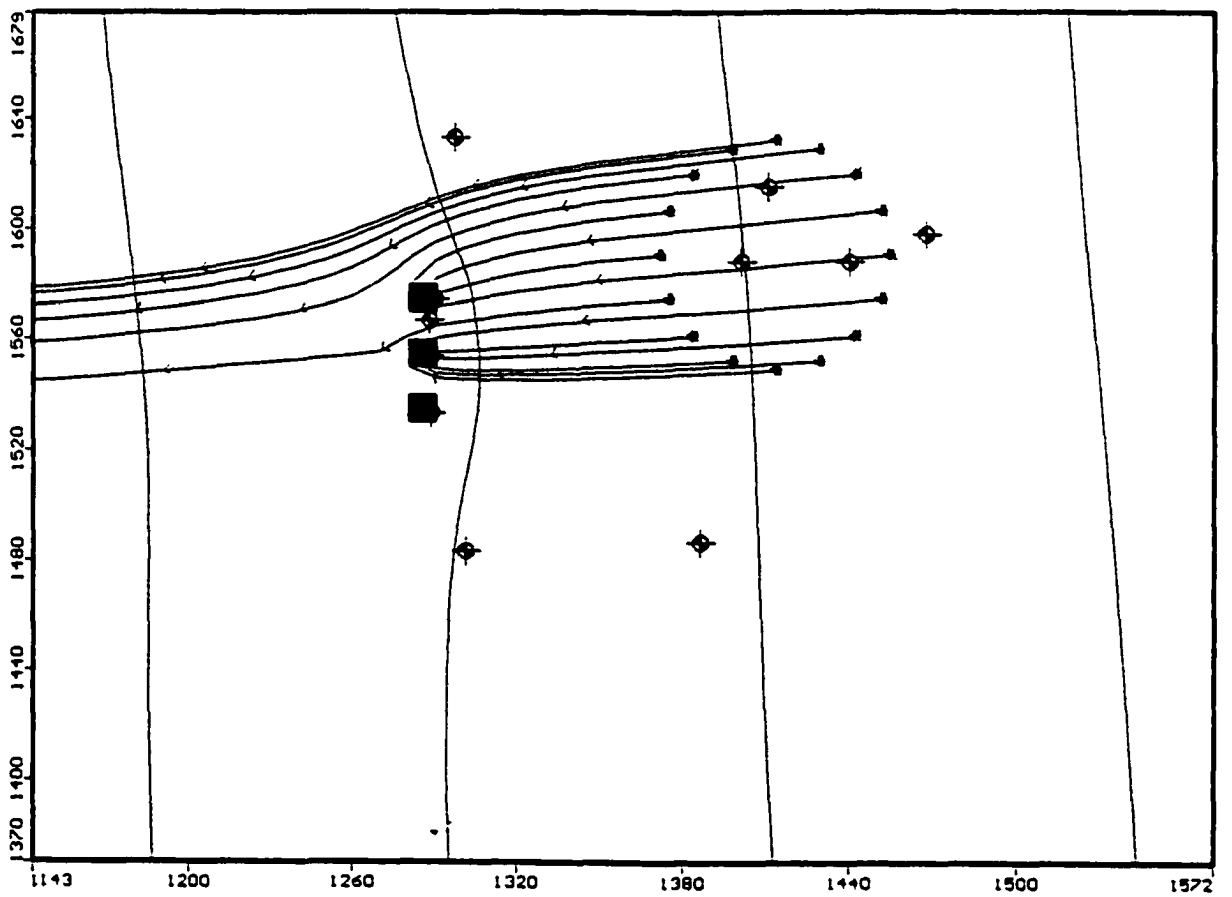
A.C. Mills – Geohydrologist
Project: NJDOT Hackettstown Yard
Description: S.S. 7D & D @ 2.5 E @ 3.
Modeller: Andy Mills
7 Aug 97

Visual MODFLOW v.1.50. (c) 1995
Waterloo Hydrogeologic Software
NC: 52 NR: 57 NL: 2
Current Layer: 1



A.C. Mills – Geohydrologist
Project: NJDOT Hackettstown Yard
Description: S.S. 7D, D & E @ 2.5
Modeller: Andy Mills
7 Aug 97

Visual MODFLOW v.1.50, (c) 1995
Waterloo Hydrogeologic Software
NC: 52 NR: 57 NL: 2
Current Layer: 1



A.C. Mills – Geohydrologist
Project: NJDOT Hackettstown Yard
Description: S.S. 7D, C & D @ 2.5
Modeller: Andy Mills
7 Aug 97

Visual MODFLOW v.1.50. (c) 1995
Waterloo Hydrogeologic Software
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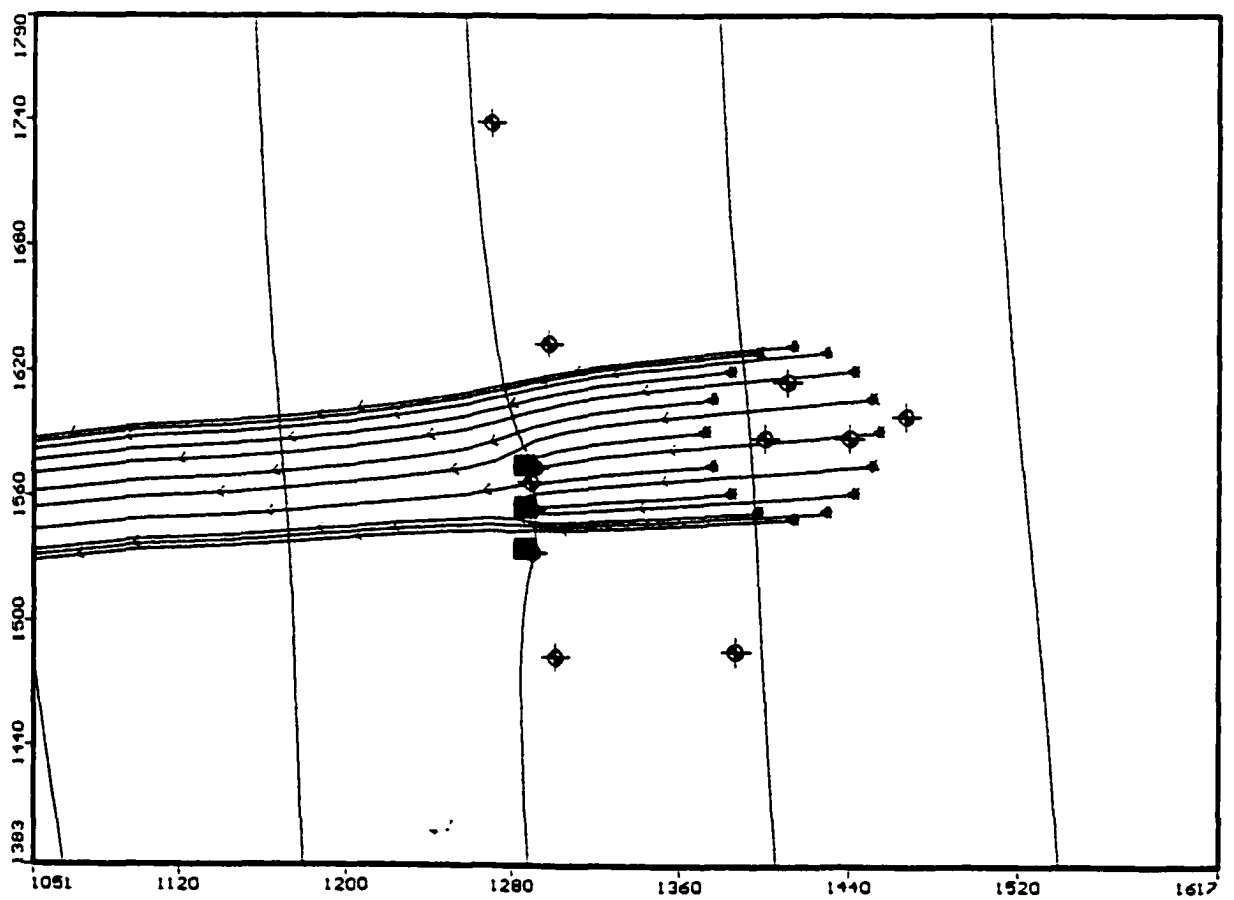
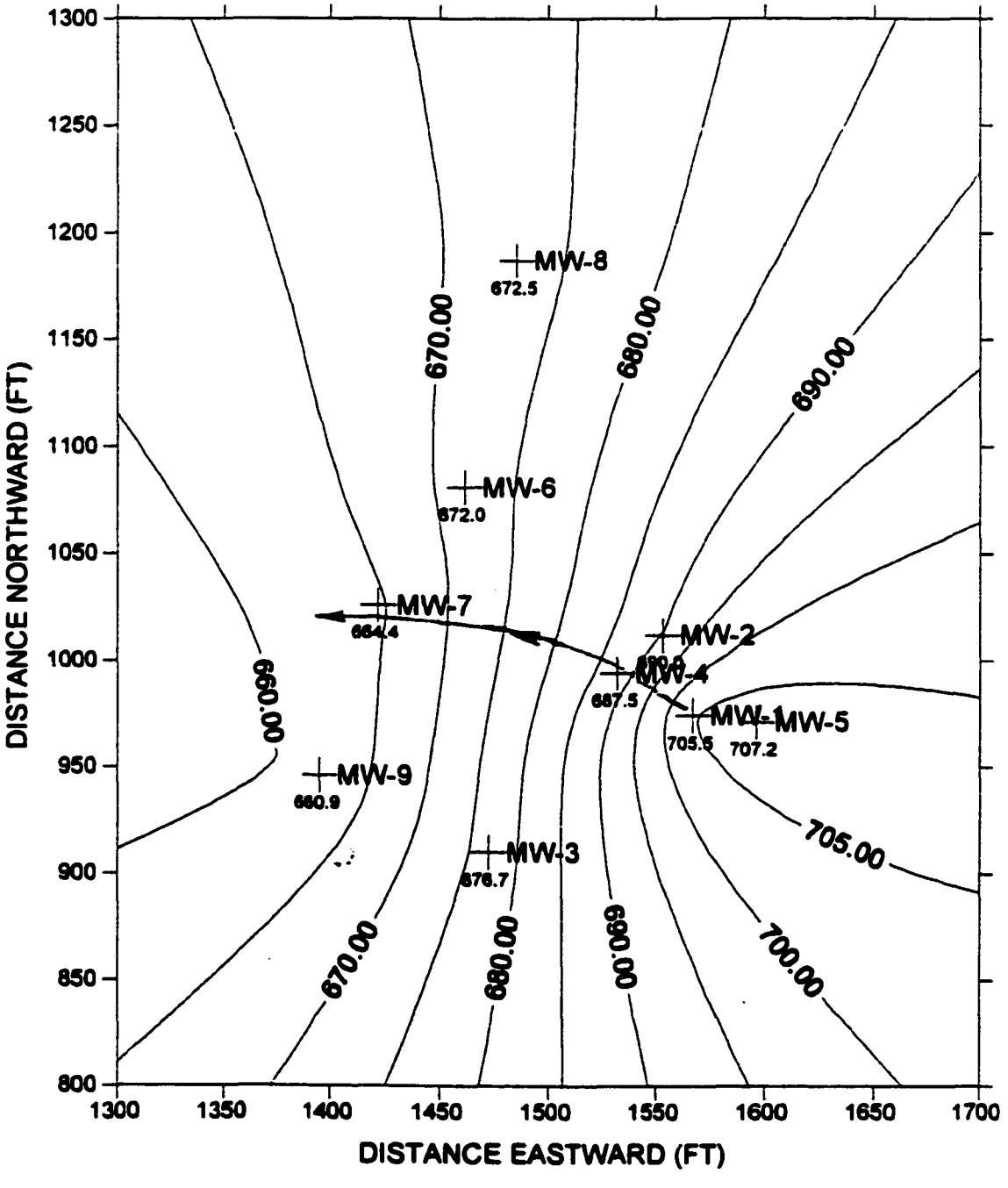
Current Layer: 1

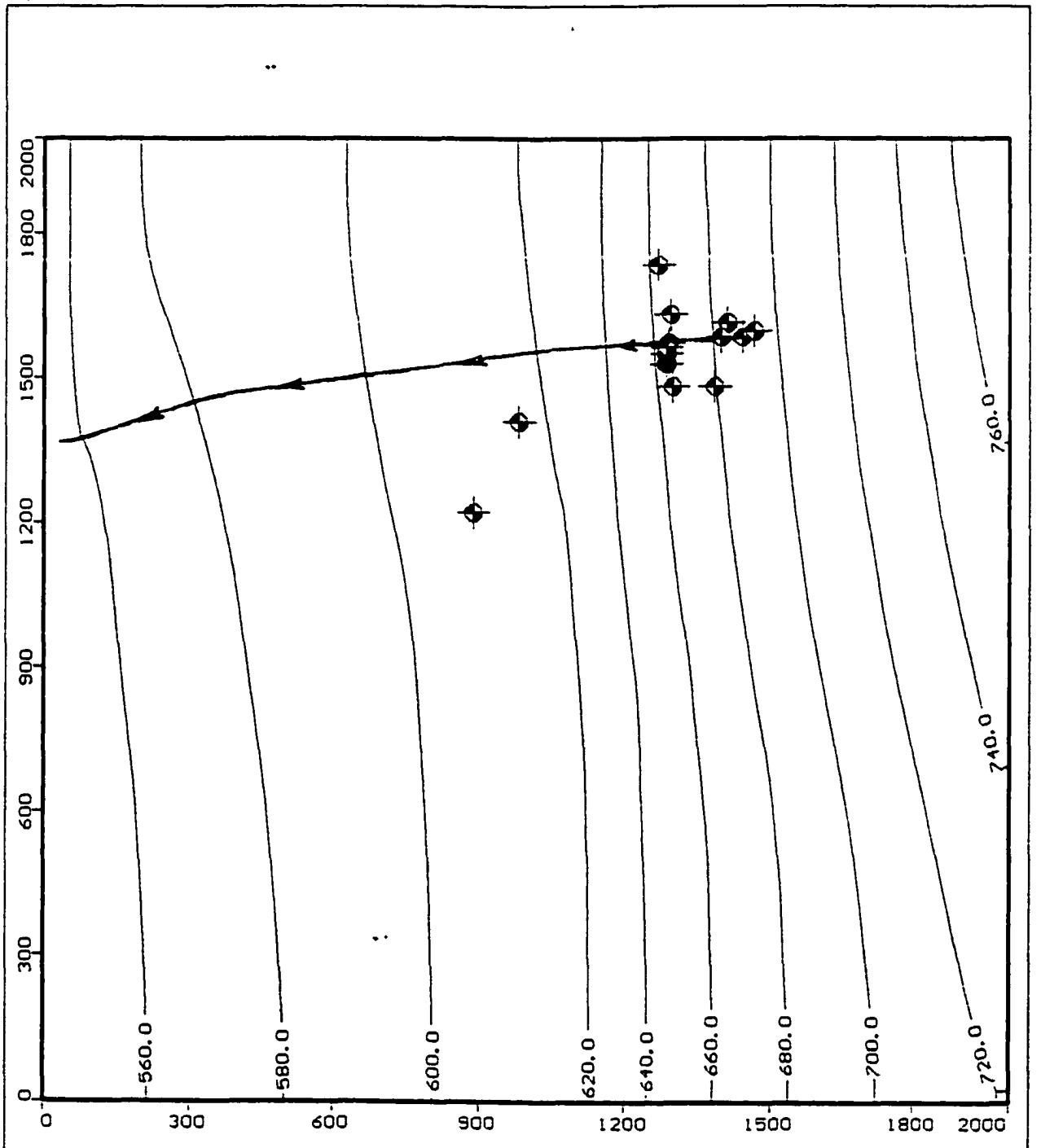


A.C. Mills – Geohydrologist
Project: NJDOT Hackettstown Yard
Description: S.S. 7D, C & D @1.4
Modeller: Andy Mills
7 Aug 97

Visual MODFLOW v.1.50. (c) 1995
Waterloo Hydrogeologic Software
NC: 52 NR: 56 NL: 2
Current Layer: 1

STATIC GROUNDWATER ELEVATION CONTOURS AT NJDOT HACKETTSTOWN FACILITY FOR JUNE 25, 1997





A.C. Mills — Geohydrologist
Project: NJDOT Hackettstown Yard
Description: Steady State Calibrated
Modeller: Andy Mills
7 Aug 97

Visual MODFLOW v.1.50. (c) 1995
Waterloo Hydrogeologic Software
NC: 52 NR: 56 NL: 2
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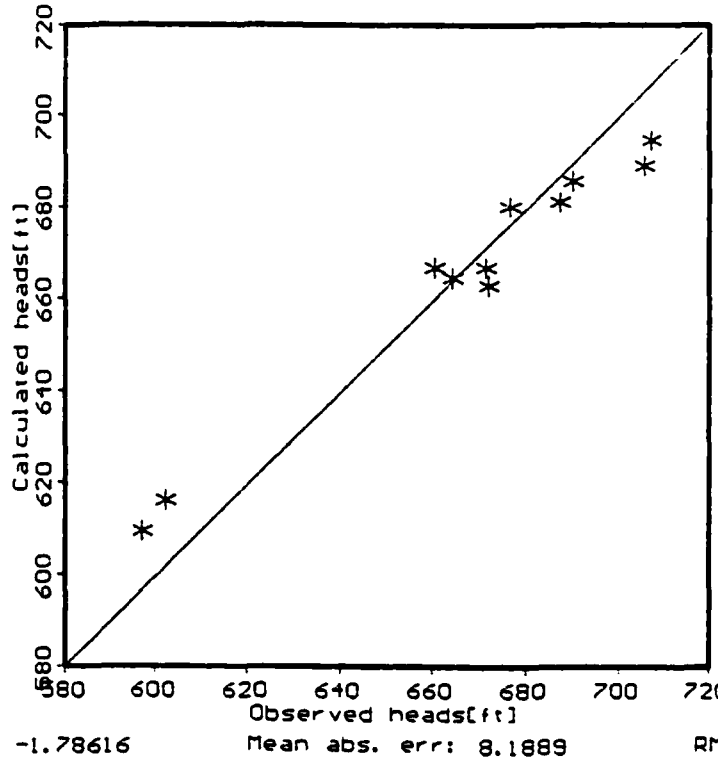


Mean error: -1.78616 Mean abs. err: 8.1889 RMS error: 9.53647

Final Calibration Run

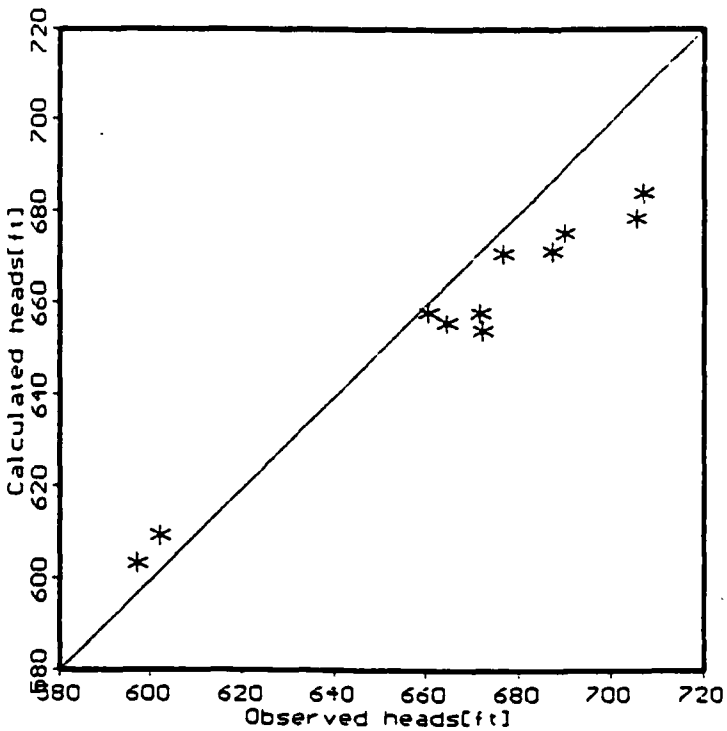
Const. Head on far eastern column ranges from 778' on north to 720' on south

Const. Head on far western column ranges from 543' on north to 542' on south

Layer 1 has K_h = 6.0 ft/day at x distances of 0 to 1100'

= 1.5 ft/day at x distances of 1100' to 2000' eastward

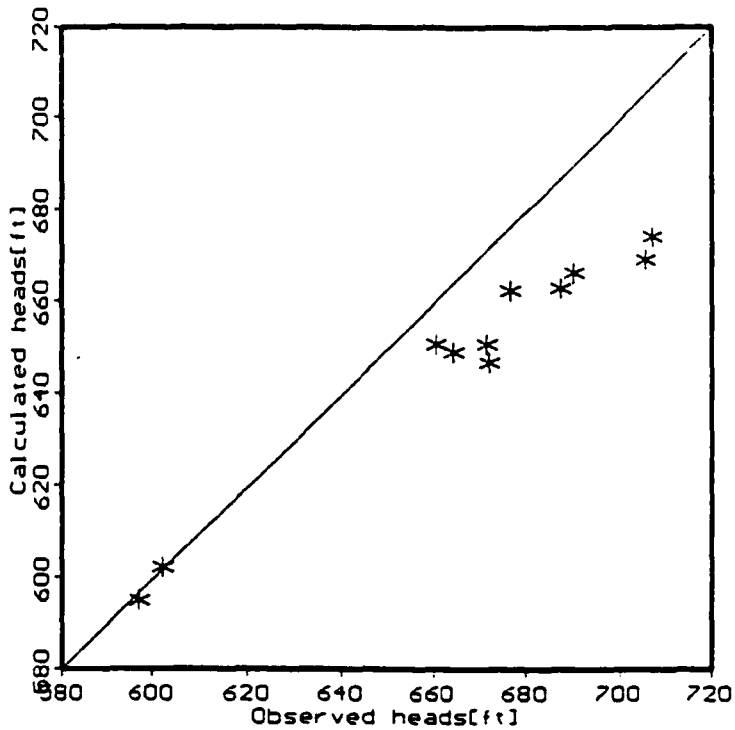
A.C. Mills — Geohydrologist Project: NJDOT Hackettstown Yard Description: Steady State Cal. Last 1 Modeller: Andy Mills 7 Aug 97	Visual MODFLOW v.1.50. (c) 1995 Waterloo Hydrogeologic Software NC: 52 NR: 56 NL: 2 Current Layer: 1



Period: 1
Step: 1

Mean error: -10.8047 Mean abs. err: 13.2205 RMS error: 15.1444

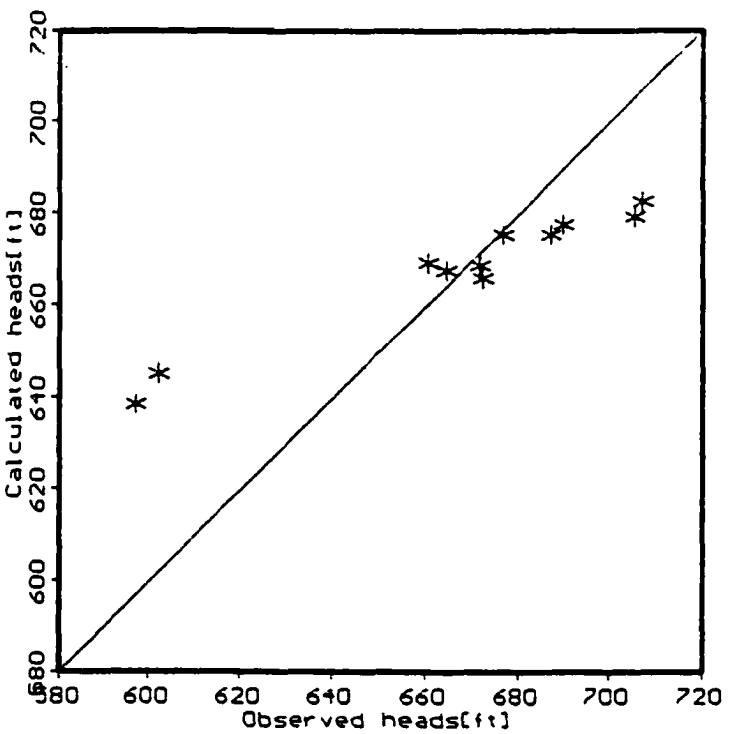
A.C. Mills – Geohydrologist Project: NJDOT Hackettstown Yard Description: Steady State Cal. Run 5 Modeller: Andy Mills 7 Aug 97	Visual MODFLOW v.1.50. (c) 1995 Waterloo Hydrogeologic Software NC: 52 NR: 56 NL: 2 Current Layer: 1



Period: 1
Step: 1

Mean error: -18.951 Mean abs. err: 18.951 RMS error: 21.992

A.C. Mills – Geohydrologist Project: NJDOT Hackettstown Yard Description: Steady State Cal. Run 4 Modeller: Andy Mills 7 Aug 97	Visual MODFLOW v.1.50. (c) 1995 Waterloo Hydrogeologic Software NC: 52 NR: 56 NL: 2 Current Layer: 1

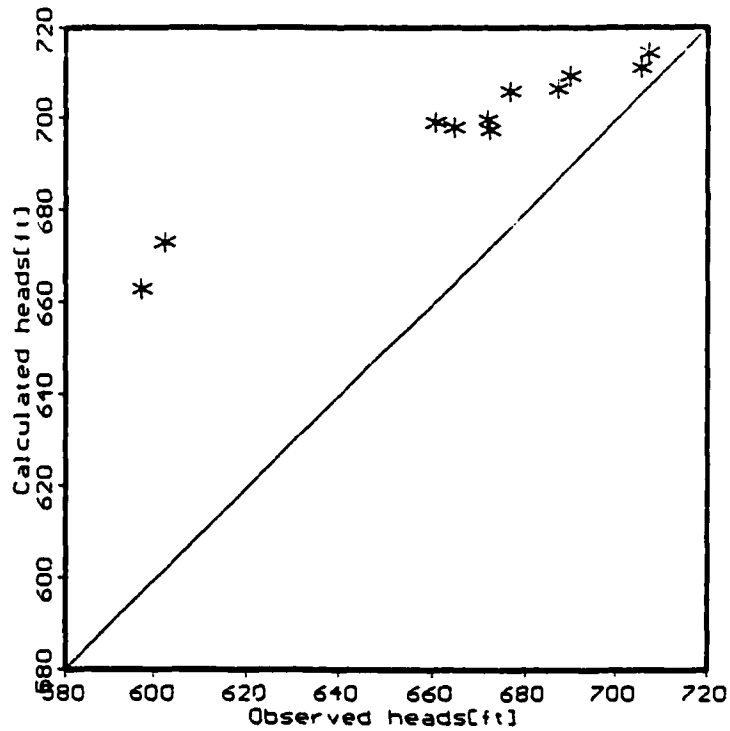


Period: 1
Step: 1

Mean error: 0.5941151 Mean abs. err: 16.6361 RMS error: 21.8948

A.C. Mills – Geohydrologist
Project: NJDOT Hackettstown Yard
Description: Steady State Cal. Run 3
Modeller: Andy Mills
7 Aug 97

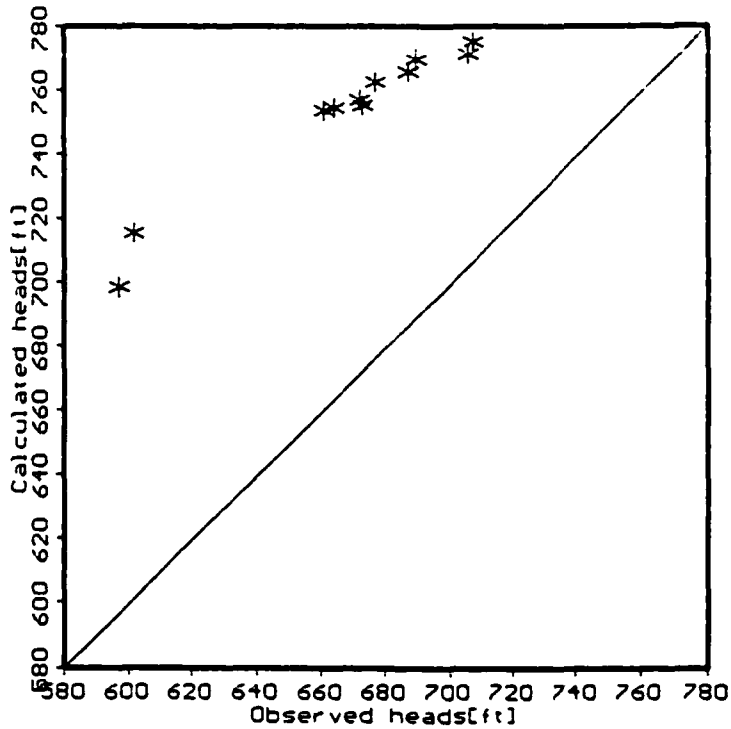
Visual MODFLOW v.1.50. (c) 1995
Waterloo Hydrogeologic Software
NC: 52 NR: 56 NL: 2
Current Layer: 1



Period: 1
Step: 1

Mean error: 30.9515 Mean abs. err: 30.9515 RMS error: 36.9314

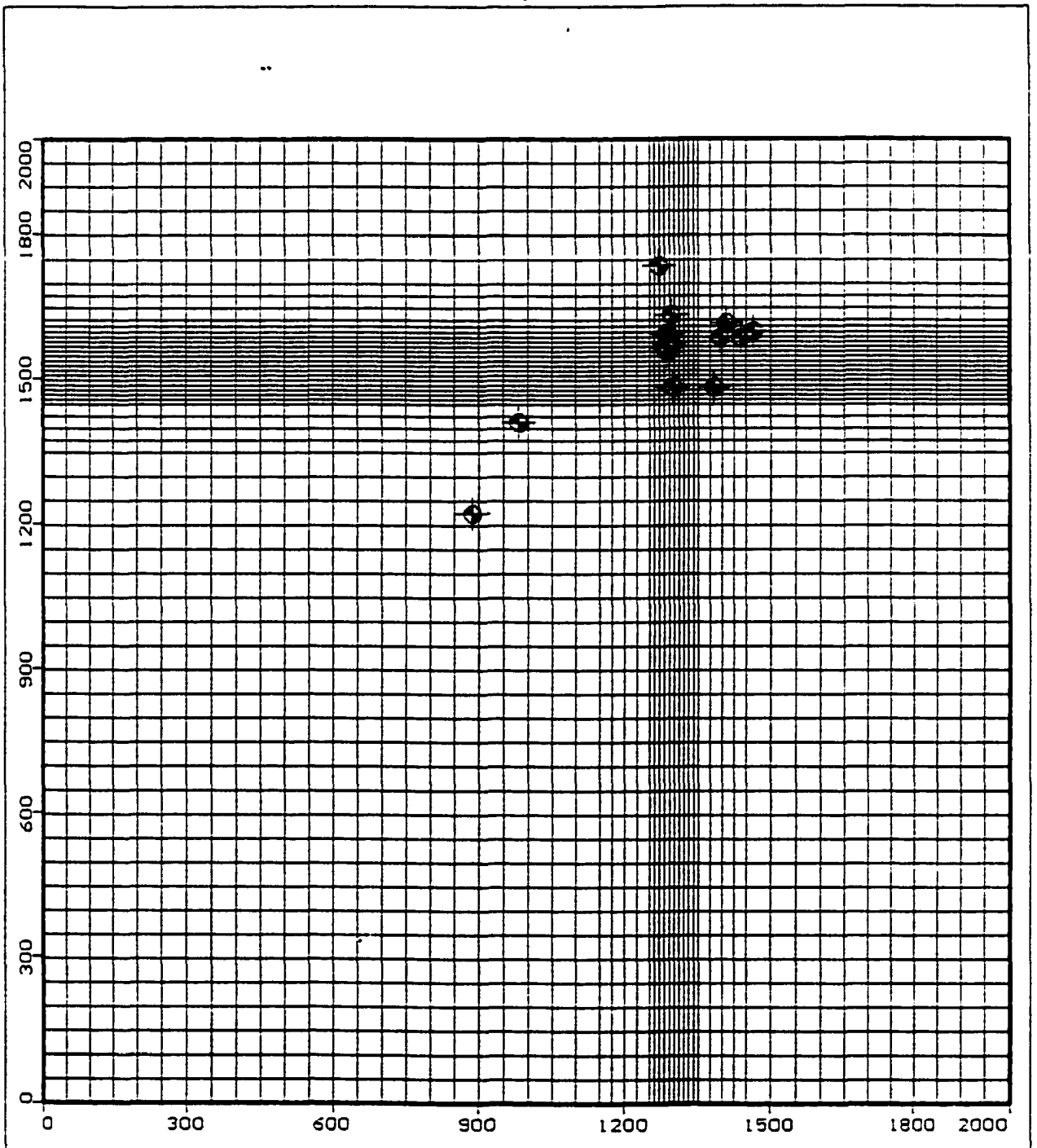
A.C. Mills — Geohydrologist Project: NJDOT Hackettstown Yard Description: Steady State Cal. Run 2 Modeller: Andy Mills 7 Aug 97	Visual MODFLOW v.1.50. (c) 1996 Waterloo Hydrogeologic Software NC: 52 NR: 56 NL: 2 Current Layer: 1



Period: 1
Step: 1

Mean error: 85.4349 Mean abs. err: 85.4349 RMS error: 86.4441

A.C. Mills – Geohydrologist Project: NJDOT Hackettstown Yard Description: Steady State Cal. Run 1 Modeller: Andy Mills 7 Aug 97	Visual MODFLOW v.1.50, (c) 1995 Waterloo Hydrogeologic Software NC: 52 NR: 56 NL: 2 Current Layer: 1



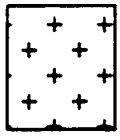
A.C. Mills — Geohydrologist
Project: NJDOT Hackettstown Yard
Description: New Rotated Moved Grid
Modeller: Andy Mills
7 Aug 97

Visual MODFLOW v.1.50. (c) 1995
Waterloo Hydrogeologic Software
NC: 52 NR: 57 NL: 2
Current Layer: 1

Appendix 2

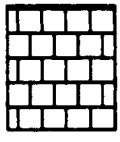
LEGEND

TOPSOIL

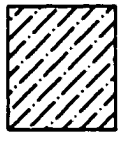


FILL: Predominantely coarse to fine sand, some silt and silty clay.

GLACIALTILL: Predominantely silty clay with some sand or coarse to fine sand, with some silty clay.



SAPROLITE: Highly weathered granite or gneiss bedrock in the form of medium to fine sand.



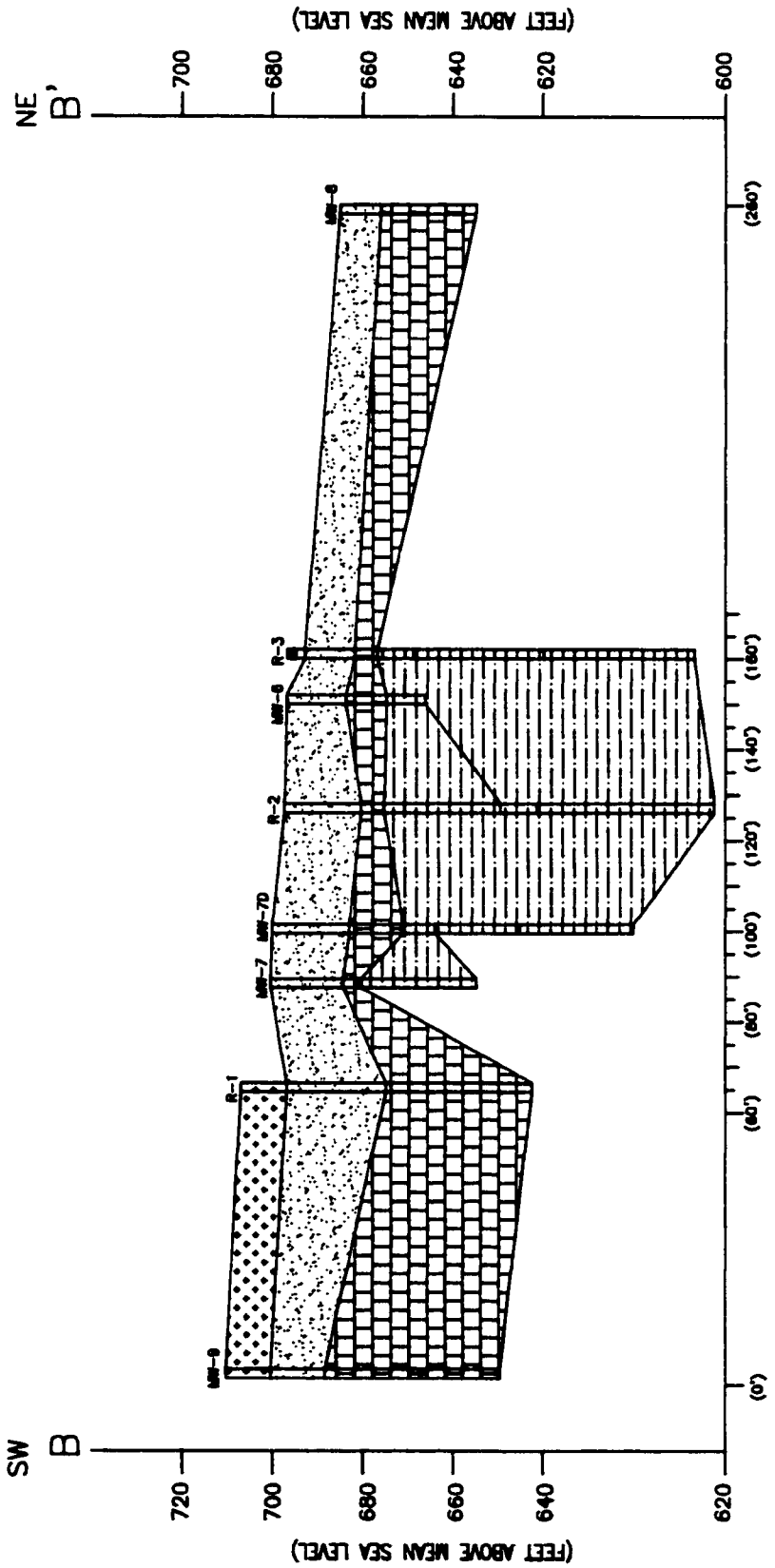
BEDROCK Granite/Gneiss

B= Boring

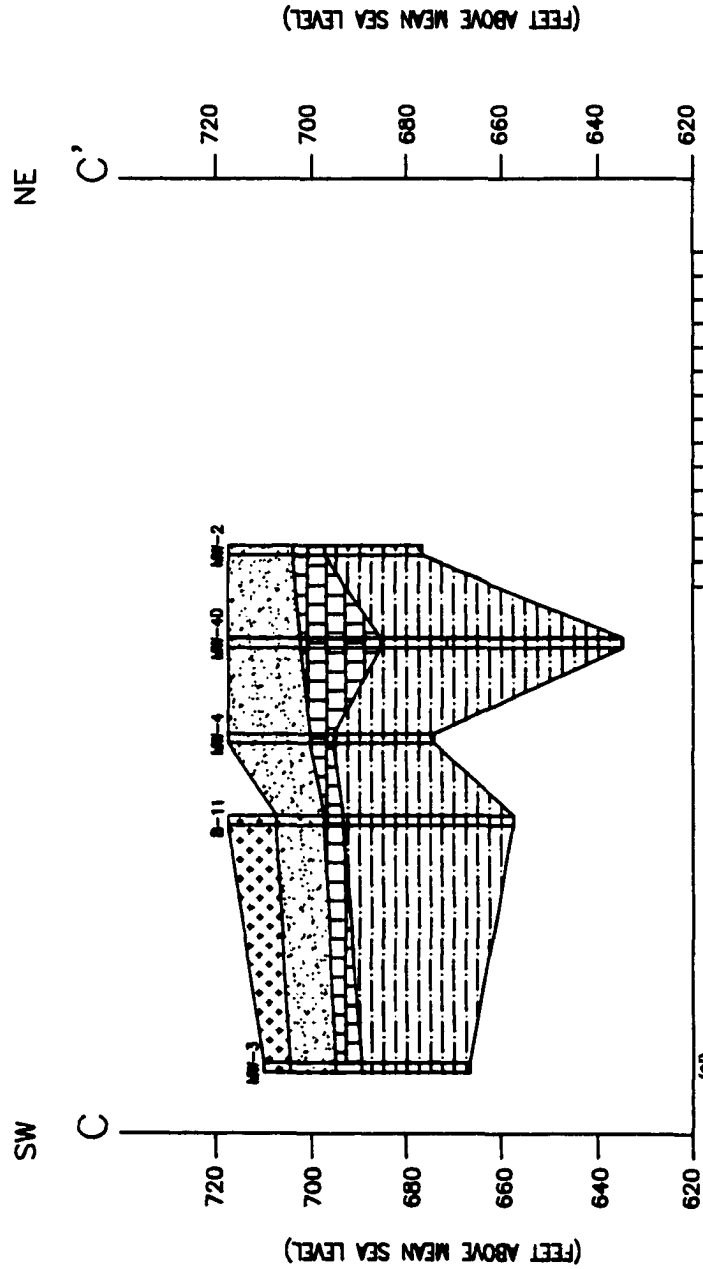
MW= Monitoring Well

PR= Product recovery well

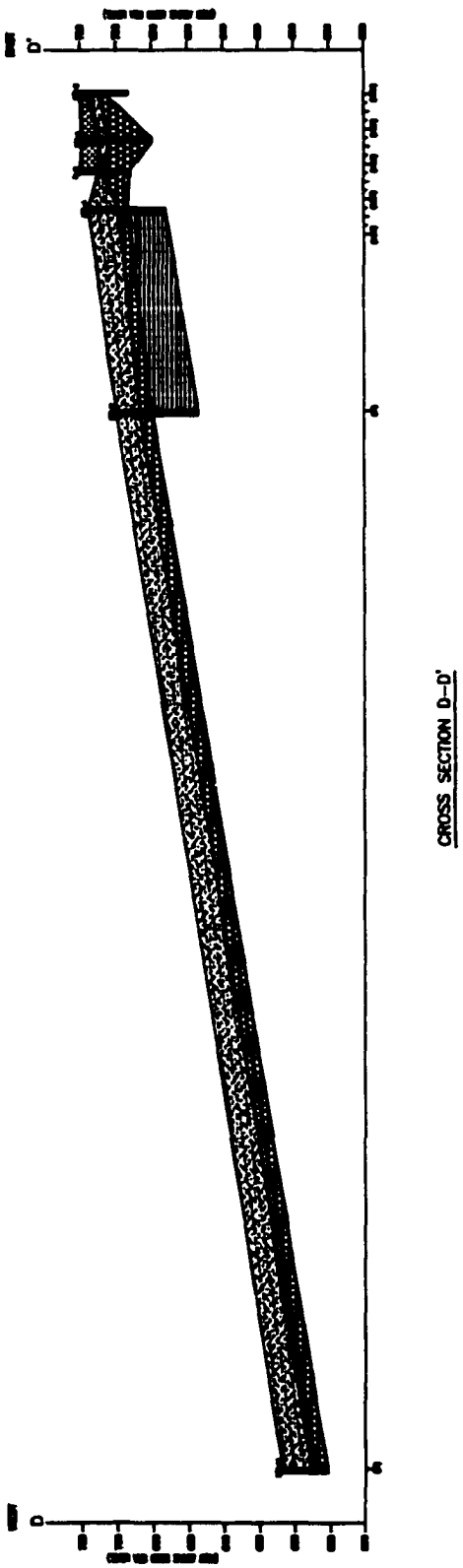
R= Recovery well

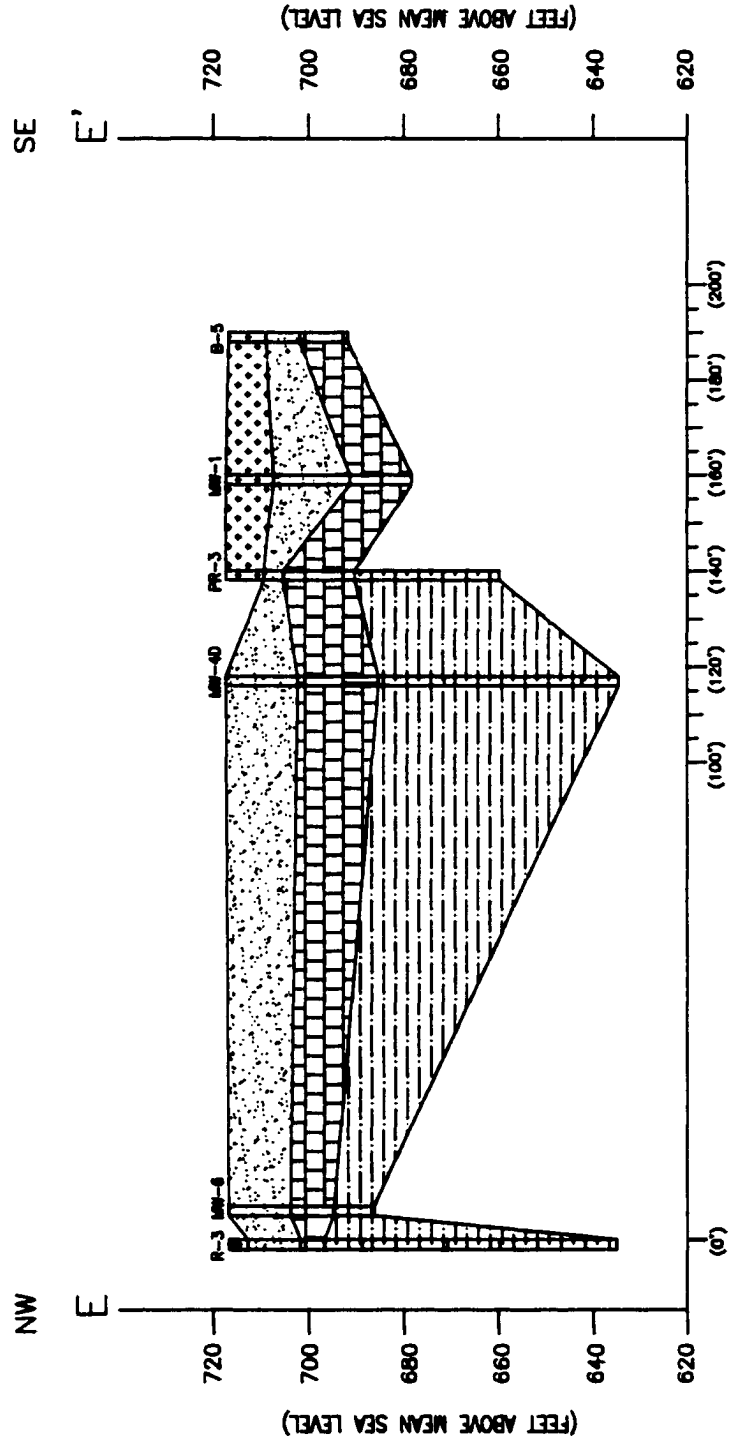


CROSS SECTION B-B'



CROSS SECTION C–C'





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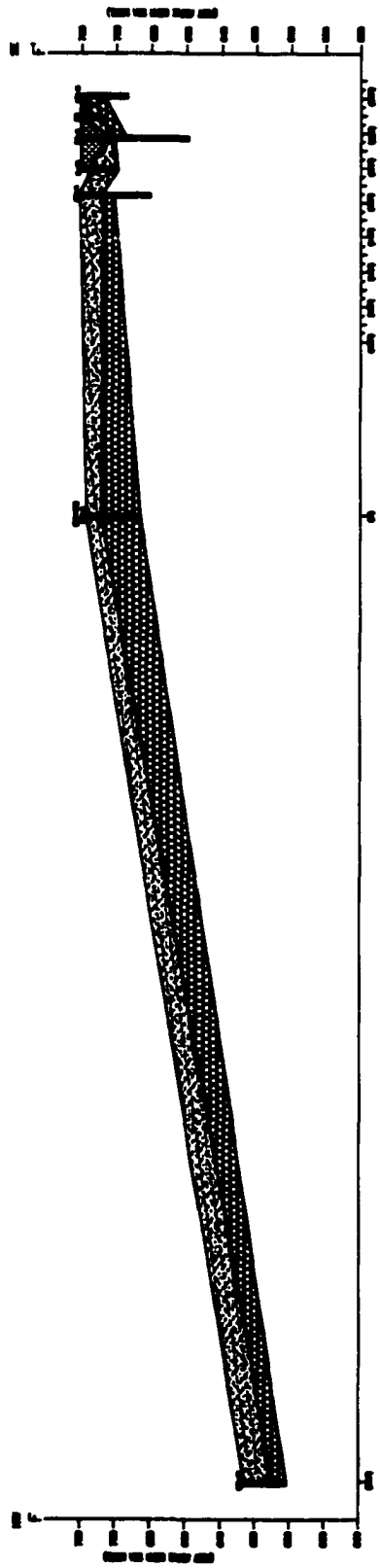
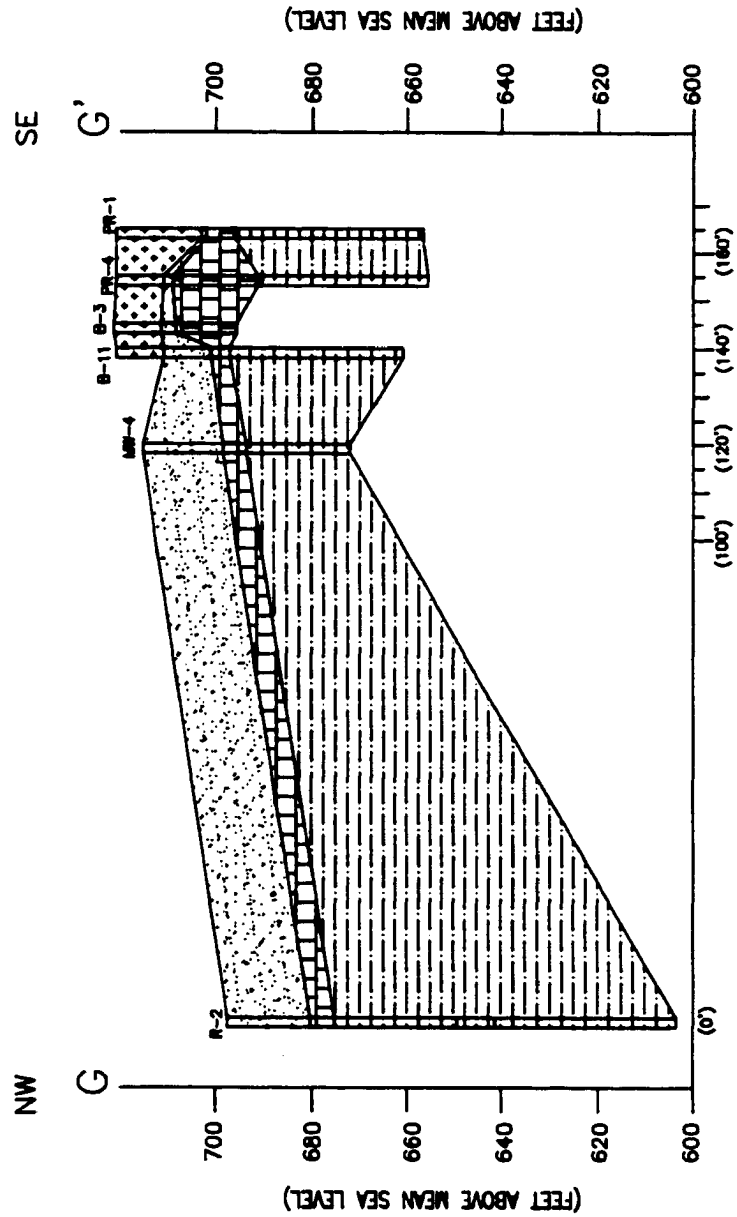


CROSS SECTION F-F'



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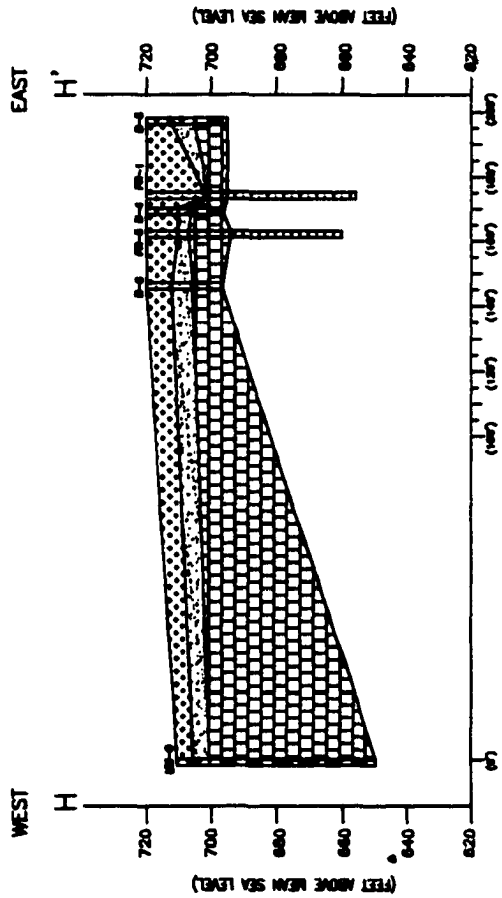
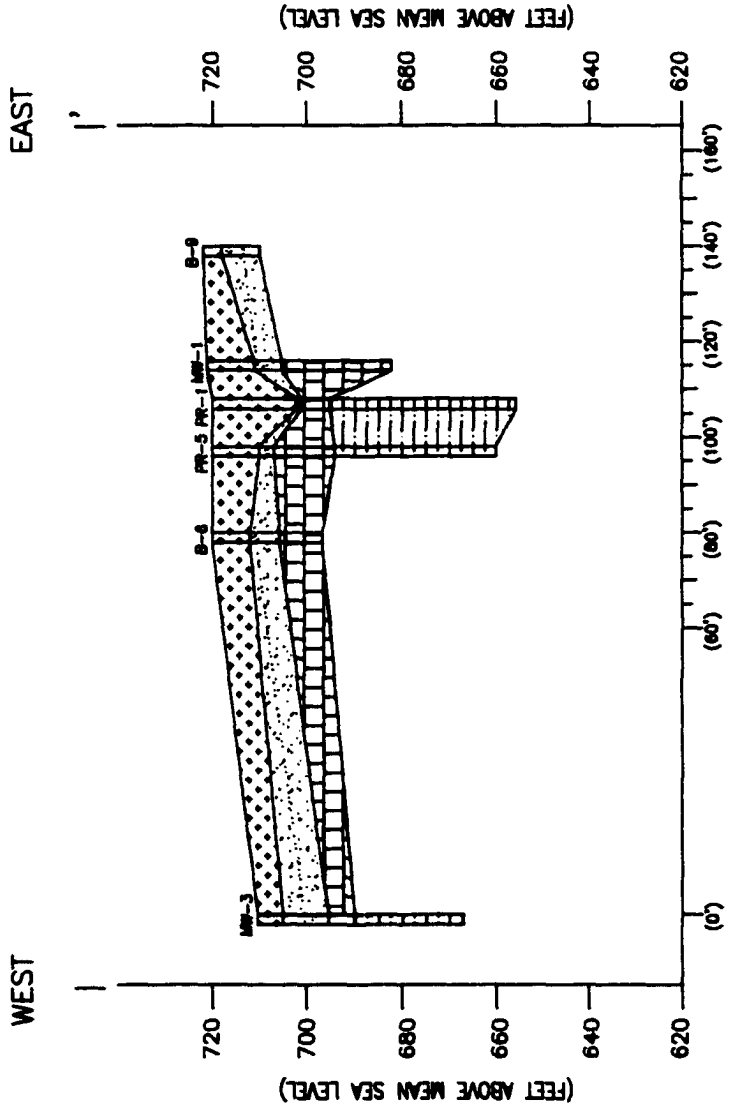
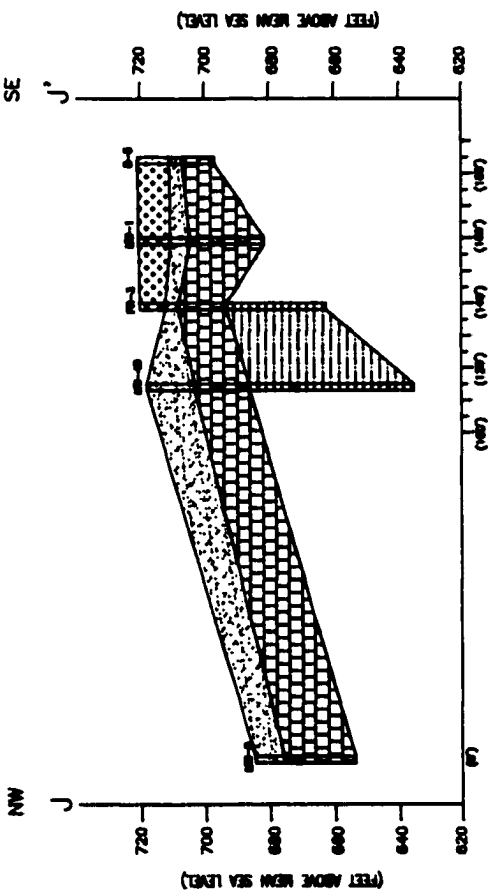


CROSS SECTION H–H'



CROSS SECTION I–I'



CROSS SECTION J–J'

Appendix 3

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

	Shallow Monitoring Wells:								
Well Name:	MW-1			MW-2*		MW-3*		MW-4*	
Measuring Point Elevation (ft amsl):	720.39 (1)			720.08		709.76		717.95	
Date	Depth to Water (ft bmp)	Depth to Product (ft bmp)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
10/04/96	33.05	29.18	690.81	39.48	680.60	41.43	668.33	NA	NA
10/23/96	30.97	28.88	691.60	35.19	684.89	29.19	680.57	NA	NA
10/25/96	24.02	23.91	697.13	35.83	684.25	33.52	676.24	NA	NA
11/18/96	21.81	21.74	699.31	35.13	684.95	35.91	673.85	NA	NA
11/25/96	18.59	--	702.48	34.40	685.68	37.3	672.46	NA	NA
12/17/96	7.70	--	713.37	17.56	702.52	11.32	698.44	NA	NA
01/07/97	9.18	9.15	711.91	19.85	700.23	13.82	695.94	NA	NA
02/27/97	10.97	--	710.10	21.98	698.10	25.07	684.69	NA	NA
03/03/97	11.73	--	709.34	22.73	697.35	25.97	683.79	22.73	695.22
03/20/97	12.14	12.13	708.94	23.90	696.18	26.81	682.95	24.02	693.93
04/22/97	8.68	8.67	712.40	19.29	700.79	14.48	695.28	18.71	699.24
04/29/97	9.45	9.44	711.63	21.00	699.08	16.50	693.26	19.56	698.39
04/30/97	9.52	9.51	711.56	20.19	699.89	16.83	692.93	19.64	698.31
05/01/97	9.56	9.55	711.52	20.20	699.88	17.05	692.71	19.69	698.26
05/06/97	10.26	10.25	710.82	20.66	699.42	15.73	694.03	20.18	697.77
05/07/97	10.49	10.48	710.59	20.82	699.26	19.16	690.6	20.33	697.62
05/28/97	12.57	--	708.50	23.45	696.63	26.18	683.58	23.43	694.52
06/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/17/97	14.75	--	706.32	28.61	691.47	31.42	678.34	28.76	689.19
06/26/97	15.71	--	705.36	30.27	689.81	33.31	676.45	30.46	687.49
06/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/02/97	16.89	--	704.18	31.62	688.46	34.79	674.97	32.02	685.93
08/14/97	27.19	26.56	694.33	38.59	681.49	42.55	667.21	38.88	679.07
08/26/97	29.62	28.90	691.97	40.21	679.87	42.25	667.51	40.34	677.61
09/02/97	31.09	30.02	690.75	DRY	NA	DRY	NA	41.26	676.69
09/08/97	32.71	30.93	689.64	DRY	NA	DRY	NA	42.09	675.86
09/09/97	NA	NA	NA	DRY	NA	DRY	NA	42.41	675.54
09/12/97	34.24	31.52	688.79	DRY	NA	42.10	667.66	42.51	675.44
09/15/97	35.15	31.83	688.31	DRY	NA	DRY	NA	42.65	675.30
09/16/97	35.55	31.93	688.13	DRY	NA	DRY	NA	42.71	675.24
09/19/97	34.15	32.79	687.90	DRY	NA	DRY	NA	42.97	674.98
09/22/97	34.86	33.09	687.48	DRY	NA	DRY	NA	43.05	674.9
09/23/97	34.23	33.41	687.43	DRY	NA	DRY	NA	DRY	NA
09/25/97	34.81	33.61	687.12	DRY	NA	DRY	NA	DRY	NA
09/26/97	34.53	33.91	686.99	DRY	NA	DRY	NA	DRY	NA
09/29/97	35.66	34.06	686.56	DRY	NA	DRY	NA	DRY	NA
10/03/97	35.80	34.82	685.98	DRY	NA	DRY	NA	DRY	NA
10/06/97	37.03	35.70	685.00	DRY	NA	DRY	NA	DRY	NA
10/14/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
10/15/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
10/22/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
10/29/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/05/97	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/10/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/17/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/20/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/24/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/26/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/01/97	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/04/97	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/08/97	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/12/1997	DRY	--	NA	NA	NA	NA	NA	NA	NA
12/16/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/19/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/22/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/29/1997	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	Shallow Monitoring Wells: MW-1			MW-2*		MW-3*		MW-4*	
Measuring Point Elevation (ft amsl):	720.39 (1)			720.08		709.76		717.95	
Date	Depth to Water (ft bmp)	Depth to Product (ft bmp)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
12/31/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/06/98	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
01/29/98	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
02/11/98	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
02/24/98	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
03/11/98	32.68	32.32	687.97	DRY	NA	41.85	667.91	42.60	675.35
03/24/98	19.44	--	700.95	37.44	682.64	38.83	670.93	37.47	680.48
03/25/98	18.57	--	701.82	36.92	683.16	39.26	670.50	37.11	680.84
03/27/98	16.52	--	703.87	35.40	684.68	37.92	671.84	35.91	682.04
03/28/98	15.60	--	704.79	34.74	685.34	37.76	672.00	35.41	682.54
04/06/98	9.59	--	710.80	25.73	694.35	29.91	679.85	27.47	690.48
04/29/98	NA	NA	NA	19.05	701.03	12.62	697.14	18.25	699.7
04/30/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/98	8.18	8.15	712.23	19.24	700.84	13.11	696.65	18.36	699.59
05/11/98	7.72	7.71	712.68	NA	NA	NA	NA	NA	NA
05/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/26/98	8.45	--	711.94	NA	NA	NA	NA	NA	NA
06/01/98	8.87	--	711.52	NA	NA	NA	NA	NA	NA
06/08/98	10.37	--	710.02	20.73	699.35	16.71	693.05	20.19	697.76
06/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/22/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/29/98	11.55	--	708.84	NA	NA	NA	NA	NA	NA
07/01/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/06/98	15.90	--	704.49	27.45	692.63	28.39	681.37	27.47	690.48
07/20/98	18.19	--	702.20	NA	NA	NA	NA	NA	NA
08/03/98	22.90	--	697.49	NA	NA	NA	NA	NA	NA
08/10/98	23.10	--	697.29	30.30	689.78	29.42	680.34	28.21	689.74
09/01/98	28.27	--	692.12	DRY	NA	DRY	NA	41.52	676.43
09/14/98	NA	NA	NA	NA	NA	NA	NA	DRY	NA
09/21/98	NA	NA	NA	NA	NA	NA	NA	DRY	NA
09/28/98	NA	NA	NA	NA	NA	NA	NA	DRY	NA
10/01/98	39.11	37.31	682.58	DRY	NA	DRY	NA	DRY	NA
10/05/98	38.76	38.72	681.66	DRY	NA	DRY	NA	DRY	NA
10/13/98	DRY	--	NA	NA	NA	NA	NA	NA	NA
10/15/98	NA	NA	NA	NA	NA	NA	NA	DRY	NA
10/19/98	DRY	--	NA	NA	NA	NA	NA	DRY	NA
10/22/98	DRY	NA	NA	DRY	NA	NA	NA	DRY	NA
10/26/98	DRY	--	NA	NA	NA	NA	NA	DRY	NA
10/27/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/02/98	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
11/11/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/18/98	DRY	--	NA	NA	NA	NA	NA	NA	NA
11/25/98	DRY	--	NA	NA	NA	NA	NA	DRY	NA
12/01/98	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
12/04/98	DRY	--	NA	NA	NA	NA	NA	NA	NA
12/07/98	DRY	--	NA	NA	NA	NA	NA	NA	NA
12/09/98	DRY	--	NA	NA	NA	NA	NA	DRY	NA
12/16/98	DRY	--	NA	NA	NA	NA	NA	NA	NA
12/24/98	DRY	--	NA	NA	NA	NA	NA	NA	NA
01/12/99	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
01/20/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/21/99	DRY	--	NA	NA	NA	NA	NA	NA	NA
02/02/99	DRY	--	NA	DRY	NA	DRY	NA	DRY	NA
02/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/19/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/22/99	NA	NA	NA	NA	NA	NA	NA	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

	Shallow Monitoring Wells:								
Well Name:	MW-1			MW-2*		MW-3*		MW-4*	
Measuring Point Elevation (ft amsl):	720.39 (1)			720.08		709.76		717.95	
Date	Depth to Water (ft bmp)	Depth to Product (ft bmp)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
02/23/99	DRY	--	NA	NA	NA	NA	NA	NA	NA
03/04/99	DRY	--	NA	DRY	NA	DRY	NA	39.51	678.44
03/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/12/99	DRY	--	NA	NA	NA	NA	NA	NA	NA
03/18/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/25/99	35.65	--	684.74	NA	NA	NA	NA	NA	NA
03/26/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/30/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/06/99	19.17	--	701.22	DRY	NA	DRY	NA	40.54	677.41
04/13/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/22/99	12.86	--	707.53	NA	NA	NA	NA	NA	NA
04/29/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/06/99	14.45	--	705.94	30.99	689.09	41.51	668.25	31.58	686.37

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Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	MW-5*		MW-6*		MW-7		MW-8		MW-9	
Measuring Point Elevation (ft amsl):	721.01		698.60		702.46		684.52		710.18	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
10/04/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/23/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/18/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/17/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/27/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/03/97	NA	NA	21.98[3]	676.62	33.66	668.80	NA	NA	NA	NA
03/20/97	9.94[3]	711.44	21.95	676.65	33.62	668.84	NA	NA	NA	NA
04/22/97	6.29	714.72	14.05	684.55	26.62	675.84	NA	NA	NA	NA
04/29/97	7.36	713.65	15.53	683.07	27.32	675.14	NA	NA	NA	NA
04/30/97	7.52	713.49	15.69	682.91	27.56	674.90	NA	NA	NA	NA
05/01/97	7.52	713.49	15.78	682.82	27.66	674.80	NA	NA	NA	NA
05/06/97	8.43	712.58	17.10	681.50	28.94	673.52	NA	NA	NA	NA
05/07/97	8.67	712.34	17.38	681.22	29.18	673.28	NA	NA	NA	NA
05/28/97	11.07	709.94	21.77	676.83	33.35	669.11	NA	NA	NA	NA
06/06/97	NA	NA	23.03	675.57	34.46	668.00	7.60	676.92	46.31	663.87
06/17/97	13.32	707.69	25.13	673.47	36.14	666.32	10.78	673.74	47.79	662.39
06/26/97	14.32	706.69	26.57	672.03	38.07	664.39	12.00	672.52	49.32	660.86
06/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/02/97	15.67	705.34	26.72	671.88	38.59	663.87	13.21	671.31	50.31	659.87
08/14/97	25.52	695.49	DRY	NA	43.91	658.55	18.81	665.71	55.38	654.80
08/26/97	DRY	NA	DRY	NA	DRY	NA	20.18	664.34	57.37	652.81
09/02/97	DRY	NA	DRY	NA	DRY	668.18	21.11	663.41	58.24	651.94
09/08/97	DRY	NA	DRY	NA	DRY	668.18	21.85	662.67	58.97	651.21
09/09/97	DRY	NA	DRY	NA	DRY	NA	22.16	662.36	59.29	650.89
09/12/97	DRY	NA	DRY	NA	DRY	NA	22.24	662.28	59.34	650.84
09/15/97	DRY	NA	DRY	NA	DRY	NA	22.44	662.08	59.80	650.38
09/16/97	DRY	NA	DRY	NA	DRY	NA	22.45	662.07	59.83	650.35
09/19/97	DRY	NA	DRY	NA	DRY	NA	22.90	661.62	60.09	650.09
09/22/97	DRY	NA	DRY	NA	DRY	NA	23.31	661.21	60.37	649.81
09/23/97	DRY	NA	DRY	NA	DRY	NA	23.41	661.11	60.32	649.86
09/25/97	DRY	NA	DRY	NA	DRY	NA	23.67	660.85	60.36	649.82
09/26/97	DRY	NA	DRY	NA	DRY	NA	23.80	660.72	DRY	NA
09/29/97	DRY	NA	DRY	NA	DRY	NA	24.23	660.29	DRY	NA
10/03/97	DRY	NA	DRY	NA	DRY	NA	24.31	660.21	DRY	NA
10/06/97	DRY	NA	DRY	NA	DRY	NA	25.10	659.42	DRY	NA
10/14/1997	DRY	NA	DRY	NA	DRY	NA	26.32	658.2	DRY	NA
10/15/1997	DRY	NA	DRY	NA	DRY	NA	26.44	658.08	DRY	NA
10/22/1997	DRY	NA	DRY	NA	DRY	NA	27.42	657.1	DRY	NA
10/29/1997	DRY	NA	DRY	NA	DRY	NA	28.18	656.34	DRY	NA
11/05/97	DRY	NA	DRY	NA	DRY	NA	28.50	656.02	DRY	NA
11/10/1997	DRY	NA	DRY	NA	DRY	NA	28.69	655.83	DRY	NA
11/17/1997	DRY	NA	DRY	NA	DRY	NA	28.56	655.96	DRY	NA
11/20/1997	DRY	NA	DRY	NA	DRY	NA	29.63	654.89	DRY	NA
11/24/1997	DRY	NA	DRY	NA	DRY	NA	29.90	654.62	DRY	NA
11/26/1997	DRY	NA	DRY	NA	DRY	NA	29.29	655.23	DRY	NA
12/01/97	DRY	NA	DRY	NA	DRY	NA	30.01	654.51	DRY	NA
12/04/97	DRY	NA	DRY	NA	DRY	NA	30.02	654.50	DRY	NA
12/08/97	DRY	NA	DRY	NA	DRY	NA	30.02	654.50	DRY	NA
12/12/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/16/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/19/1997	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
12/22/1997	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
12/29/1997	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA

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Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	MW-5*		MW-6*		MW-7		MW-8		MW-9	
Measuring Point Elevation (ft amsl):	721.01		698.60		702.46		684.52		710.18	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
12/31/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/06/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
01/29/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
02/11/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
02/24/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
03/11/98	25.90	695.11	DRY	NA	DRY	NA	24.79	659.73	DRY	NA
03/24/98	13.80	707.21	DRY	NA	DRY	NA	18.68	665.84	DRY	NA
03/25/98	13.52	707.49	DRY	NA	45.16	657.30	18.97	665.55	DRY	NA
03/27/98	12.10	708.91	DRY	NA	45.14	657.32	17.27	667.25	59.90	650.28
03/28/98	11.53	709.48	DRY	NA	45.16	657.30	16.67	667.85	59.79	650.39
04/06/98	6.89	714.12	28.49	670.11	42.88	659.58	10.50	674.02	54.11	656.07
04/29/98	5.82	715.19	12.77	685.83	23.21	679.25	NA	NA	33.69	676.49
04/30/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/98	4.87	716.14	13.85	684.75	25.18	677.28	1.24	683.28	34.60	675.58
05/11/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/18/98	NA	NA	14.20	684.40	23.03	679.43	NA	NA	NA	NA
05/26/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/01/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/08/98	8.56	712.45	18.35	680.25	29.31	673.15	2.14	682.38	39.41	670.77
06/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/22/98	NA	NA	20.50	678.10	31.43	671.03	NA	NA	NA	NA
06/29/98	NA	NA	22.97	675.63	34.55	667.91	NA	NA	NA	NA
07/01/98	NA	NA	25.14	673.46	35.43	667.03	NA	NA	NA	NA
07/06/98	14.43	706.58	26.96	671.64	36.87	665.59	10.77	673.75	47.09	663.09
07/20/98	NA	NA	29.38	669.22	39.95	662.51	NA	NA	NA	NA
08/03/98	NA	NA	30.07	668.53	DRY	NA	NA	NA	NA	NA
08/10/98	22.10	698.91	36.94	661.66	DRY	NA	13.10	671.42	59.50	650.68
09/01/98	26.38	694.63	DRY	NA	DRY	NA	24.85	659.67	DRY	NA
09/14/98	NA	NA	DRY	NA	DRY	NA	29.21	655.31	NA	NA
09/21/98	NA	NA	DRY	NA	DRY	NA	28.73	655.79	NA	NA
09/28/98	NA	NA	DRY	NA	DRY	NA	DRY	NA	NA	NA
10/01/98	DRY	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/05/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
10/13/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/15/98	NA	NA	DRY	NA	DRY	NA	DRY	NA	NA	NA
10/19/98	NA	NA	DRY	NA	DRY	NA	DRY	NA	NA	NA
10/22/98	DRY	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/26/98	NA	NA	DRY	NA	DRY	NA	DRY	NA	NA	NA
10/27/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/02/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
11/11/98	NA	NA	DRY	NA	DRY	NA	NA	NA	NA	NA
11/18/98	NA	NA	DRY	NA	DRY	NA	NA	NA	NA	NA
11/25/98	NA	NA	DRY	NA	DRY	NA	DRY	NA	NA	NA
12/01/98	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
12/04/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/07/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/09/98	NA	NA	DRY	NA	DRY	NA	DRY	NA	NA	NA
12/16/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/24/98	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/12/99	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
01/20/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/21/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/02/99	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
02/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/19/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/22/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	MW-5*		MW-6*		MW-7		MW-8		MW-9	
Measuring Point Elevation (ft amsl):	721.01		698.60		702.46		684.52		710.18	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
02/23/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/04/99	DRY	NA	DRY	NA	DRY	NA	DRY	NA	DRY	NA
03/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/12/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/18/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/25/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/26/99	NA	NA	DRY	NA	45.16	657.30	DRY	NA	NA	NA
03/30/99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/06/99	13.15	707.86	DRY	NA	DRY	NA	26.31	658.21	DRY	NA
04/15/99	NA	NA	DRY	NA	DRY	NA	20.39	664.13	NA	NA
04/22/99	NA	NA	DRY	NA	DRY	NA	18.37	666.15	NA	NA
04/29/99	NA	NA	DRY	NA	DRY	NA	16.59	667.93	NA	NA
05/06/99	12.83	708.18	DRY	NA	DRY	NA	16.98	667.54	58.20	651.98

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	MW-10		MW-11		MW-12		Product Delineation Wells: PR-1		
Measuring Point Elevation (ft amsl):	605.43		607.11		626.63			720.19	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)
10/04/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/23/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/18/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/17/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/27/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/03/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/20/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/22/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/29/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/01/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/28/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/17/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/26/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/02/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
08/14/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
08/26/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/02/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/08/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/09/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/12/97	17.21	588.22	19.50	587.61	20.13	606.50	NA	NA	NA
09/15/97	17.38	588.05	19.70	587.41	20.31	606.32	NA	NA	NA
09/16/97	17.47	587.96	19.81	587.30	20.43	606.20	NA	NA	NA
09/19/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/22/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/23/97	18.02	587.41	20.17	586.94	20.93	605.70	NA	NA	NA
09/25/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/26/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/29/97	18.54	586.89	20.62	586.49	21.27	605.36	NA	NA	NA
10/03/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/14/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/15/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/22/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/29/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/05/97	NA	NA	NA	NA	NA	NA	49.02	49.01	671.18
11/10/1997	19.41	586.02	22.63	584.48	23.83	602.8	46.36	46.15	673.98
11/17/1997	NA	NA	NA	NA	NA	NA	46.91	46.69	673.44
11/20/1997	NA	NA	NA	NA	NA	NA	47.17	46.88	673.23
11/24/1997	NA	NA	NA	NA	NA	NA	47.53	47.28	672.84
11/26/1997	NA	NA	NA	NA	NA	NA	49.52	49.50	670.68
12/01/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/04/97	NA	NA	NA	NA	NA	NA	53.65	53.61	666.57
12/08/97	NA	NA	NA	NA	NA	NA	48.77	48.75	671.43
12/12/1997	NA	NA	NA	NA	NA	NA	49.60	49.55	670.63
12/16/1997	NA	NA	NA	NA	NA	NA	49.62	49.59	670.59
12/19/1997	NA	NA	NA	NA	NA	NA	49.98	49.97	670.22
12/22/1997	24.16	581.27	DRY	NA	DRY	NA	NA	NA	NA
12/29/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	MW-10		MW-11		MW-12		Product Delineation Wells: PR-1		
Measuring Point Elevation (ft amsl):	605.43		607.11		626.63			720.19	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)
12/31/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/06/98	26.42	579.01	DRY	NA	DRY	NA	49.89	--	670.30
01/29/98	NA	NA	NA	NA	NA	NA	48.19	48.18	672.01
02/11/98	NA	NA	NA	NA	NA	NA	48.71	48.70	671.49
02/24/98	NA	NA	NA	NA	NA	NA	48.69	--	671.50
03/11/98	21.98	583.45	24.67	582.44	23.24	603.39	39.34	--	680.85
03/24/98	NA	NA	NA	NA	NA	NA	21.41	--	698.78
03/25/98	NA	NA	NA	NA	NA	NA	20.20	--	699.99
03/27/98	NA	NA	NA	NA	NA	NA	18.03	--	702.16
03/28/98	NA	NA	NA	NA	NA	NA	17.10	--	703.09
04/06/98	19.25	586.18	21.26	585.85	20.28	606.35	9.24	--	710.95
04/29/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/30/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/98	14.06	591.37	16.59	590.52	12.49	614.14	7.92	--	712.27
05/11/98	NA	NA	NA	NA	NA	NA	7.04	--	713.15
05/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/26/98	NA	NA	NA	NA	NA	NA	7.16	--	713.03
06/01/98	NA	NA	NA	NA	NA	NA	8.18	--	712.01
06/08/98	5.51	599.92	7.99	599.12	8.44	618.19	9.56	--	710.63
06/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/22/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/29/98	NA	NA	NA	NA	NA	NA	13.93	--	706.26
07/01/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/06/98	8.24	597.19	10.74	596.37	10.79	615.84	15.38	--	704.81
07/20/98	NA	NA	NA	NA	NA	NA	18.02	--	702.17
08/03/98	NA	NA	NA	NA	NA	NA	21.75	--	698.44
08/10/98	12.35	593.08	15.44	591.67	15.26	611.37	22.30	--	697.89
09/01/98	14.79	590.64	17.80	589.31	18.66	607.97	34.78	--	685.41
09/14/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/21/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/28/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/01/98	NA	NA	NA	NA	NA	NA	42.60	42.55	677.63
10/05/98	18.10	587.33	20.84	586.27	21.71	604.92	43.84	--	676.35
10/13/98	NA	NA	NA	NA	NA	NA	43.71	--	676.48
10/15/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/19/98	NA	NA	NA	NA	NA	NA	44.96	--	675.23
10/22/98	NA	NA	NA	NA	NA	NA	45.53	--	674.66
10/26/98	NA	NA	NA	NA	NA	NA	46.59	46.58	673.61
10/27/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/02/98	20.42	585.01	22.87	584.24	23.64	602.99	48.37	48.35	671.83
11/11/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/18/98	NA	NA	NA	NA	NA	NA	54.18	54.16	666.02
11/25/98	NA	NA	NA	NA	NA	NA	52.21	52.10	668.06
12/01/98	22.58	582.85	24.78	582.33	DRY	NA	53.25	53.15	667.01
12/04/98	NA	NA	NA	NA	NA	NA	53.56	53.54	666.64
12/07/98	NA	NA	NA	NA	NA	NA	54.06	54.03	666.15
12/09/98	NA	NA	NA	NA	NA	NA	54.34	54.33	665.86
12/16/98	NA	NA	NA	NA	NA	NA	56.20	--	663.99
12/24/98	NA	NA	NA	NA	NA	NA	56.31	--	663.88
01/12/99	25.19	580.24	DRY	NA	DRY	NA	58.67	58.66	661.53
01/20/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/21/99	NA	NA	NA	NA	NA	NA	58.72	58.71	661.48
02/02/99	24.98	580.45	DRY	NA	DRY	NA	53.17	--	667.02
02/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/19/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/22/99	NA	NA	NA	NA	NA	NA	NA	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	MW-10		MW-11		MW-12		Product Delineation Wells: PR-1		
Measuring Point Elevation (ft amsl):	605.43		607.11		626.63			720.19	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)
02/23/99	NA	NA	NA	NA	NA	NA	53.75	--	666.44
03/04/99	DRY	NA	DRY	NA	DRY	NA	NA	NA	NA
03/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/12/99	NA	NA	NA	NA	NA	NA	55.64	--	664.55
03/18/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/25/99	NA	NA	NA	NA	NA	NA	41.75	--	678.44
03/26/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/30/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/06/99	22.10	583.33	DRY	NA	DRY	NA	21.18	--	699.01
04/15/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/22/99	NA	NA	NA	NA	NA	NA	13.46	Sheen	706.73
04/29/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/06/99	20.69	584.74	23.31	583.80	21.25	605.38	15.19	--	705.00

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:		PR-2			PR-3			PR-4	
Measuring Point Elevation (ft amsl):		720.97			720.13			720.33	
Date	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)
10/04/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/23/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/18/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/17/96	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/27/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/03/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/20/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/22/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/29/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/01/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/28/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/17/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/26/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/02/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
08/14/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
08/26/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/02/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/08/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/09/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/12/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/15/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/16/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/19/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/22/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/23/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/25/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/26/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/29/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/03/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/14/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/15/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/22/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/29/1997	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/05/97	41.51	41.45	679.50	50.19	--	669.94	50.20	--	670.13
11/10/1997	41.09	40.82	680.07	48.72	--	671.41	49.13	--	671.20
11/17/1997	41.92	41.38	679.44	49.26	--	670.87	49.90	49.75	670.54
11/20/1997	42.33	41.60	679.17	49.48	--	670.65	50.14	49.98	670.31
11/24/1997	42.89	41.87	678.81	49.78	--	670.35	50.46	50.31	669.98
11/26/1997	43.20	42.00	678.63	49.96	--	670.17	50.64	50.49	669.80
12/01/97	43.83	42.40	678.17	50.45	--	669.68	51.11	50.95	669.34
12/04/97	44.20	42.64	677.89	50.78	--	669.35	51.42	51.25	669.03
12/08/97	44.70	43.01	677.49	50.32	--	669.81	51.84	51.66	668.62
12/12/1997	44.21	43.68	677.14	51.55	51.50	668.62	52.22	52.08	668.21
12/16/1997	44.68	44.01	676.77	NA	NA	NA	NA	NA	NA
12/19/1997	45.66	45.26	675.60	52.24	52.20	667.92	52.95	52.82	667.47
12/22/1997	45.50	45.21	675.68	52.61	52.56	667.56	53.70	53.67	666.65
12/29/1997	46.70	46.60	674.34	53.13	53.08	667.04	54.12	54.11	666.22

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:		PR-2			PR-3			PR-4	
Measuring Point Elevation (ft amsl):		720.97			720.13			720.33	
Date	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)
12/31/1997	NA	NA	NA	NA	NA	NA	54.09	54.08	666.25
01/06/98	46.46	46.45	674.52	51.75	51.74	668.39	52.35	--	667.98
01/29/98	45.97	45.96	675.01	50.06	50.05	670.08	50.73	50.72	669.61
02/11/98	45.29	45.21	675.74	51.12	51.09	669.03	52.05	52.04	668.29
02/24/98	42.85	42.68	678.24	49.09	49.06	671.06	50.02	--	670.31
03/11/98	33.62	33.58	687.38	44.21	44.20	675.93	48.98	--	671.35
03/24/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/25/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/27/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/28/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/06/98	12.66	--	708.31	25.83	--	694.30	26.26	--	694.07
04/29/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/30/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/04/98	10.27	--	710.70	18.60	--	701.53	18.53	18.52	701.81
05/11/98	9.17	--	711.80	17.17	--	702.96	17.12	--	703.21
05/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/26/98	9.34	--	711.63	17.84	--	702.29	17.29	17.28	703.05
06/01/98	10.49	--	710.48	18.86	--	701.27	18.89	--	701.44
06/08/98	12.22	--	708.75	20.11	--	700.02	20.33	--	700.00
06/18/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/22/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/29/98	14.41	--	706.56	24.47	--	695.66	22.33	22.31	698.01
07/01/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/06/98	18.58	--	702.39	27.27	--	692.86	27.69	--	692.64
07/20/98	21.15	--	699.82	31.17	--	688.96	31.43	31.42	688.91
08/03/98	24.88	24.85	696.11	34.94	--	685.19	33.21	--	687.12
08/10/98	25.01	24.99	695.97	35.29	--	684.84	33.82	--	686.51
09/01/98	32.17	31.86	689.02	41.09	--	679.04	41.38	--	678.95
09/14/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/21/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
09/28/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/01/98	38.85	38.56	682.33	47.81	--	672.32	48.25	--	672.08
10/05/98	39.02	38.94	682.01	48.22	--	671.91	48.61	--	671.72
10/13/98	39.01	38.90	682.04	47.57	--	672.56	47.93	--	672.40
10/15/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/19/98	39.85	39.61	681.29	48.91	--	671.22	49.35	--	670.98
10/22/98	40.55	40.18	680.69	49.61	49.59	670.53	50.10	--	670.23
10/26/98	41.43	40.91	679.91	50.91	50.69	669.38	51.29	--	669.04
10/27/98	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/02/98	42.46	41.55	679.17	52.26	52.20	667.91	52.78	--	667.55
11/11/98	43.93	43.08	677.65	53.65	--	666.48	NA	NA	NA
11/18/98	44.89	44.03	676.70	54.78	--	665.35	55.50	--	664.83
11/25/98	45.23	45.11	675.83	56.10	55.75	664.03	56.75	--	663.58
12/01/98	45.95	45.81	675.12	56.83	56.73	663.30	57.62	57.61	662.72
12/04/98	46.39	46.22	674.70	56.95	--	663.18	58.98	--	661.35
12/07/98	46.85	46.59	674.31	57.24	--	662.89	59.44	--	660.89
12/09/98	47.02	46.88	674.05	57.28	--	662.85	59.75	--	660.58
12/16/98	47.69	47.66	673.30	DRY	--	NA	60.13	--	660.20
12/24/98	47.88	47.84	673.12	DRY	--	NA	60.21	--	660.12
01/12/99	50.13	50.11	670.85	DRY	--	NA	61.89	--	658.44
01/20/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/21/99	50.24	50.20	670.76	DRY	--	NA	61.84	--	658.49
02/02/99	48.67	--	672.30	DRY	--	NA	61.80	--	658.53
02/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/19/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/22/99	NA	NA	NA	NA	NA	NA	NA	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:		PR-2			PR-3			PR-4	
Measuring Point Elevation (ft amsl):		720.97			720.13			720.33	
Date	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)	Depth to Water (ft bmp)	Depth to Product (ft amsl)	Water Level Elevation + (ft amsl)
02/23/99	46.44	--	674.53	DRY	--	NA	57.61	--	662.72
03/04/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/11/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/12/99	49.37	--	671.60	DRY	--	NA	59.87	--	660.46
03/18/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/25/99	35.85	35.84	685.13	45.50	--	674.63	46.15	--	674.18
03/26/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/30/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/06/99	20.13	--	700.84	40.53	--	679.60	41.11	--	679.22
04/15/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/22/99	15.07	15.06	705.91	31.36	Sheen	688.77	31.83	--	688.50
04/29/99	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/06/99	16.47	--	704.50	31.00	--	689.13	31.30	--	689.03

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Deep Monitoring Wells and Recovery Wells:

Well Name:	PR-5		MW-4D		MW-7D		R-1		R-2	
Measuring Point Elevation (ft amsl):	719.81		717.97		698.85 (2)		705.90		696.46	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation[2] (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
10/04/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/23/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/18/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11/25/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12/17/96	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
01/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/27/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/03/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/20/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/22/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/29/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
04/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/01/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/06/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/07/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05/28/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
06/06/97	NA	NA	NA	NA	33.09	667.93	NA	NA	NA	NA
06/17/97	NA	NA	29.27	688.70	34.76	666.26	NA	NA	NA	NA
06/26/97	NA	NA	30.9	687.07	38.51	662.51	NA	NA	NA	NA
06/30/97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
07/02/97	NA	NA	32.27	685.7	37.19	663.83	NA	NA	NA	NA
08/14/97	NA	NA	39.24	678.73	42.51	658.51	NA	NA	NA	NA
08/26/97	NA	NA	40.78	677.19	44.48	656.54	NA	NA	NA	NA
09/02/97	NA	NA	41.71	676.26	45.35	655.67	NA	NA	NA	NA
09/08/97	NA	NA	42.55	675.42	46.19	654.83	NA	NA	NA	NA
09/09/97	NA	NA	42.90	675.07	46.53	654.49	NA	NA	NA	NA
09/12/97	NA	NA	43.03	674.94	46.74	654.28	NA	NA	NA	NA
09/15/97	NA	NA	43.12	674.85	46.99	654.03	NA	NA	NA	NA
09/16/97	NA	NA	43.21	674.76	47.03	653.99	NA	NA	NA	NA
09/19/97	NA	NA	43.87	674.10	45.18	653.67	NA	NA	NA	NA
09/22/97	NA	NA	43.90	674.07	45.49	653.36	NA	NA	NA	NA
09/23/97	NA	NA	43.99	673.98	45.36	653.49	NA	NA	NA	NA
09/25/97	NA	NA	44.06	673.91	45.42	653.43	NA	NA	NA	NA
09/26/97	NA	NA	44.37	673.60	45.52	653.33	NA	NA	NA	NA
09/29/97	NA	NA	44.85	673.12	46.38	652.47	NA	NA	NA	NA
10/03/97	NA	NA	44.90	673.07	46.42	652.43	NA	NA	NA	NA
10/06/97	NA	NA	46.92	671.05	NA	NA	NA	NA	NA	NA
10/14/1997	NA	NA	46.71	671.26	NA	NA	NA	NA	NA	NA
10/15/1997	NA	NA	46.86	671.11	NA	NA	NA	NA	NA	NA
10/22/1997	NA	NA	47.51	670.46	NA	NA	NA	NA	NA	NA
10/29/1997	NA	NA	48.60	669.37	NA	NA	NA	NA	NA	NA
11/05/97	49.68	670.13	48.69	669.28	NA	NA	NA	NA	NA	NA
11/10/1997	48.56	671.25	48.92	669.05	NA	NA	NA	NA	NA	NA
11/17/1997	49.20	670.61	43.05	674.92	NA	NA	NA	NA	NA	NA
11/20/1997	49.39	670.42	49.71	668.26	NA	NA	NA	NA	NA	NA
11/24/1997	49.76	670.05	49.97	668.00	53.42	645.43	NA	NA	NA	NA
11/26/1997	49.97	669.84	50.22	667.75	52.56	646.29	NA	NA	NA	NA
12/01/97	50.39	669.42	50.69	667.28	52.70	646.15	NA	NA	NA	NA
12/04/97	50.74	669.07	50.96	667.01	52.95	645.90	NA	NA	NA	NA
12/08/97	50.40	669.41	51.01	666.96	51.08	647.77	NA	NA	NA	NA
12/12/1997	51.53	668.28	NA	NA	NA	NA	NA	NA	NA	NA
12/16/1997	51.93	667.88	NA	NA	NA	NA	NA	NA	NA	NA
12/19/1997	52.26	667.55	51.92	666.05	NA	NA	NA	NA	NA	NA
12/22/1997	52.29	667.52	52.84	665.13	NA	NA	NA	NA	NA	NA
12/29/1997	52.99	666.82	53.24	664.73	NA	NA	NA	NA	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Deep Monitoring Wells and Recovery Wells:

Well Name:	PR-5		MW-4D		MW-7D		R-1		R-2	
Measuring Point Elevation (ft amsl):	719.81		717.97		698.85 (2)		705.90		696.46	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation[2] (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
12/31/1997	52.97	666.84	NA	NA	NA	NA	NA	NA	NA	NA
01/06/98	51.58	668.23	51.83	666.14	NA	NA	NA	NA	NA	NA
01/29/98	49.61	670.20	49.91	668.06	NA	NA	NA	NA	NA	NA
02/11/98	50.99	668.82	51.20	666.77	NA	NA	NA	NA	51.32	645.14
02/24/98	48.96	670.85	49.36	668.61	51.88	646.97	59.05	646.85	48.85	647.61
03/11/98	44.12	675.69	44.68	673.29	NA	NA	62.40	643.50	47.80	648.66
03/24/98	NA	NA	38.52	679.45	46.77	652.08	54.11	651.79	41.59	654.87
03/25/98	NA	NA	38.12	679.85	45.93	652.92	53.22	652.68	41.55	654.91
03/27/98	NA	NA	36.75	681.22	44.13	654.72	51.44	654.46	39.34	657.12
03/28/98	NA	NA	36.19	681.78	50.52	648.33	63.37	642.53	41.72	654.74
04/06/98	25.87	693.94	28.23	689.74	41.84	657.01	46.41	659.49	33.89	662.57
04/29/98	NA	NA	18.71	699.26	19.93	678.92	26.65	679.25	17.87	678.59
04/30/98	NA	NA	NA	NA	27.74	671.11	28.37	677.53	54.41	642.05
05/04/98	17.34	702.47	19.94	698.03	22.53	676.32	29.21	676.69	77.10	619.36
05/11/98	16.11	703.70	NA	NA	NA	NA	NA	NA	NA	NA
05/18/98	NA	NA	NA	NA	22.97	675.88	26.31	679.59	18.41	678.05
05/26/98	NA	NA	NA	NA	22.38	676.47	27.95	677.95	90.21	606.25
06/01/98	NA	NA	NA	NA	24.08	674.77	27.89	678.01	86.91	609.55
06/08/98	19.28	700.53	20.95	697.02	26.01	672.84	32.81	673.09	54.02	642.44
06/18/98	NA	NA	NA	NA	23.17	675.68	31.25	674.65	77.15	619.31
06/22/98	NA	NA	NA	NA	28.35	670.50	34.93	670.97	56.28	640.18
06/29/98	21.07	698.74	NA	NA	31.60	667.25	38.04	667.86	73.61	622.85
07/01/98	NA	NA	NA	NA	30.07	668.78	37.29	668.61	29.47	666.99
07/06/98	26.91	692.90	28.28	689.69	33.75	665.10	37.50	668.40	41.06	655.40
07/20/98	30.84	688.97	NA	NA	38.41	660.44	43.31	662.59	51.70	644.76
08/03/98	34.69	685.12	NA	NA	50.54	648.31	52.74	653.16	NA	NA
08/10/98	34.90	684.91	30.27	687.70	48.41	650.44	53.62	652.28	NA	NA
09/01/98	40.87	678.94	42.34	675.63	67.74	631.11	64.75	641.15	89.10	607.36
09/14/98	NA	NA	45.57	672.40	76.52	622.33	66.05	639.85	90.92	605.54
09/21/98	NA	NA	46.68	671.29	76.80	622.05	81.90	624.00	89.61	606.85
09/28/98	NA	NA	45.48	672.49	75.91	622.94	77.60	628.30	90.04	606.42
10/01/98	47.67	672.14	49.56	668.41	NA	NA	NA	NA	NA	NA
10/05/98	48.11	671.70	49.35	668.62	54.04	644.81	61.70	644.20	49.78	646.68
10/13/98	47.39	672.42	NA	NA	NA	NA	NA	NA	NA	NA
10/15/98	NA	NA	48.92	669.05	62.45	636.40	68.35	637.55	89.10	607.36
10/19/98	48.75	671.06	50.12	667.85	61.10	637.75	74.10	631.80	89.50	606.96
10/22/98	49.58	670.23	51.15	666.82	NA	NA	NA	NA	NA	NA
10/26/98	50.76	669.05	52.54	665.43	61.70	637.15	87.90	618.00	89.36	607.10
10/27/98	NA	NA	NA	NA	64.80	634.05	NA	NA	NA	NA
11/02/98	52.27	667.54	54.18	663.79	61.65	637.20	92.25	613.65	89.34	607.12
11/11/98	53.70	666.11	NA	NA	65.21	633.64	92.45	613.45	87.68	608.78
11/18/98	54.76	665.05	NA	NA	63.27	635.58	92.35	613.55	88.77	607.69
11/25/98	55.93	663.88	57.71	660.26	63.71	635.14	92.48	613.42	89.42	607.04
12/01/98	56.80	663.01	58.53	659.44	64.09	634.76	92.51	613.39	88.47	607.99
12/04/98	57.21	662.60	NA	NA	NA	NA	NA	NA	NA	NA
12/07/98	57.72	662.09	NA	NA	NA	NA	NA	NA	NA	NA
12/09/98	58.02	661.79	59.62	658.35	65.61	633.24	92.31	613.59	89.45	607.01
12/16/98	58.90	660.91	NA	NA	NA	NA	NA	NA	NA	NA
12/24/98	59.09	660.72	NA	NA	NA	NA	NA	NA	NA	NA
01/12/99	DRY	NA	61.89	656.08	65.52	633.33	92.50	613.40	80.01	616.45
01/20/99	NA	NA	NA	NA	73.09	625.76	72.49	633.41	79.30	617.16
01/21/99	DRY	NA	NA	NA	NA	NA	NA	NA	NA	NA
02/02/99	DRY	NA	56.94	661.03	64.03	634.82	92.60	613.30	89.85	606.61
02/11/99	NA	NA	NA	NA	66.41	632.44	85.08	620.82	76.86	619.60
02/19/99	NA	NA	NA	NA	70.71	628.14	91.87	614.03	89.74	606.72
02/22/99	NA	NA	NA	NA	73.46	625.39	92.68	613.22	89.84	606.62

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Deep Monitoring Wells and Recovery Wells:

Well Name:	PR-5		MW-4D		MW-7D		R-1		R-2	
Measuring Point Elevation (ft amsl):	719.81		717.97		698.85 (2)		705.90		696.46	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation[2] (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
02/23/99	DRY	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/04/99	NA	NA	56.76	661.21	74.63	624.22	91.96	613.94	88.41	608.05
03/11/99	NA	NA	NA	NA	76.09	622.76	NA	NA	86.24	610.22
03/12/99	DRY	NA	NA	NA	NA	NA	NA	NA	NA	NA
03/18/99	NA	NA	NA	NA	75.59	623.26	90.74	615.16	87.96	608.50
03/25/99	45.56	674.25	NA	NA	74.87	623.98	89.99	615.91	86.67	609.79
03/26/99	NA	NA	NA	NA	68.31	630.54	91.20	614.70	86.51	609.95
03/30/99	NA	NA	NA	NA	59.80	639.05	91.56	614.34	87.45	609.01
04/06/99	40.68	679.13	42.54	675.43	57.11	641.74	88.20	617.70	87.15	609.31
04/15/99	NA	NA	NA	NA	57.10	641.75	92.45	613.45	86.10	610.36
04/22/99	31.36	688.45	NA	NA	48.00	650.85	91.05	614.85	85.93	610.53
04/29/99	NA	NA	NA	NA	47.30	651.55	60.58	645.32	84.02	612.44
05/06/99	31.72	688.09	33.09	684.88	41.30	657.55	47.63	658.27	87.85	608.61

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	R-3	
Measuring Point Elevation (ft amsl):	696.20	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
10/04/96	NA	NA
10/23/96	NA	NA
10/25/96	NA	NA
11/18/96	NA	NA
11/25/96	NA	NA
12/17/96	NA	NA
01/07/97	NA	NA
02/27/97	NA	NA
03/03/97	NA	NA
03/20/97	NA	NA
04/22/97	NA	NA
04/29/97	NA	NA
04/30/97	NA	NA
05/01/97	NA	NA
05/06/97	NA	NA
05/07/97	NA	NA
05/28/97	NA	NA
06/06/97	NA	NA
06/17/97	NA	NA
06/26/97	NA	NA
06/30/97	NA	NA
07/02/97	NA	NA
08/14/97	NA	NA
08/26/97	NA	NA
09/02/97	NA	NA
09/08/97	NA	NA
09/09/97	NA	NA
09/12/97	NA	NA
09/15/97	NA	NA
09/16/97	NA	NA
09/19/97	NA	NA
09/22/97	NA	NA
09/23/97	NA	NA
09/25/97	NA	NA
09/26/97	NA	NA
09/29/97	NA	NA
10/03/97	NA	NA
10/06/97	NA	NA
10/14/1997	NA	NA
10/15/1997	NA	NA
10/22/1997	NA	NA
10/29/1997	NA	NA
11/05/97	NA	NA
11/10/1997	NA	NA
11/17/1997	NA	NA
11/20/1997	NA	NA
11/24/1997	NA	NA
11/26/1997	NA	NA
12/01/97	NA	NA
12/04/97	NA	NA
12/08/97	NA	NA
12/12/1997	NA	NA
12/16/1997	NA	NA
12/19/1997	NA	NA
12/22/1997	NA	NA
12/29/1997	NA	NA

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	R-3	
Measuring Point Elevation (ft amsl):	696.20	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
12/31/1997	NA	NA
01/06/98	NA	NA
01/29/98	NA	NA
02/11/98	NA	NA
02/24/98	43.96	652.24
03/11/98	39.91	656.29
03/24/98	34.96	661.24
03/25/98	40.76	655.44
03/27/98	33.05	663.15
03/28/98	32.68	663.52
04/06/98	26.65	669.55
04/29/98	12.51	683.69
04/30/98	15.58	680.62
05/04/98	16.52	679.68
05/11/98	NA	NA
05/18/98	14.65	681.55
05/26/98	18.37	677.83
06/01/98	17.58	678.62
06/08/98	17.50	678.70
06/18/98	22.70	673.50
06/22/98	20.05	676.15
06/29/98	22.62	673.58
07/01/98	26.29	669.91
07/06/98	26.96	669.24
07/20/98	29.82	666.38
08/03/98	36.87	659.33
08/10/98	37.11	659.09
09/01/98	46.50	649.70
09/14/98	51.04	645.16
09/21/98	46.45	649.75
09/28/98	56.00	640.20
10/01/98	NA	NA
10/05/98	45.47	650.73
10/13/98	NA	NA
10/15/98	62.09	634.11
10/19/98	54.63	641.57
10/22/98	NA	NA
10/26/98	73.40	622.80
10/27/98	76.10	620.10
11/02/98	72.84	623.36
11/11/98	74.91	621.29
11/18/98	75.52	620.68
11/25/98	75.54	620.66
12/01/98	75.55	620.65
12/04/98	NA	NA
12/07/98	NA	NA
12/09/98	75.48	620.72
12/16/98	NA	NA
12/24/98	NA	NA
01/12/99	75.60	620.60
01/20/99	75.27	620.93
01/21/99	NA	NA
02/02/99	74.45	621.75
02/11/99	75.32	620.88
02/19/99	74.40	621.80
02/22/99	75.65	620.55

See footnotes on last page.

Appendix 3

Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999

NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

Well Name:	R-3	
Measuring Point Elevation (ft amsl):	696.20	
Date	Depth to Water (ft bmp)	Water Level Elevation (ft amsl)
02/23/99	NA	NA
03/04/99	76.79	619.41
03/11/99	72.02	624.18
03/12/99	NA	NA
03/18/99	75.31	620.89
03/25/99	75.41	620.79
03/26/99	67.24	628.96
03/30/99	71.19	625.01
04/06/99	66.20	630.00
04/15/99	65.30	630.90
04/22/99	59.10	637.10
04/29/99	50.63	645.57
05/06/99	50.35	645.85

See footnotes on last page.

Appendix 3
Water-Level Elevation and Product Thickness Measurements October 1996 through May 1999
NJDOT - Hackettstown Maintenance Facility, Washington Township, New Jersey

ft amsl Feet above mean sea level
ft bmp Feet below measuring point
– Product not detected
NA Well not installed /measurement not taken
(1) Measuring point elevation was 721.07 ft amsl prior to October 14, 1997
(2) Measuring point elevation was 701.02 ft amsl prior to September 19, 1997

\+ Specific gravity of product is estimated to be 0.72 at 15°C
R Recovery well

Appendix 4

RESULTS OF ANALYSIS OF PUMPING TESTS AT NJDOT FACILITY
BASED ON DRAWDOWNS ADJUSTED FOR PRE-TEST DECLINE TREND
WASHINGTON TOWNSHIP, MORRIS COUNTY

PUMPING TEST OF R-1 (3/27-28/88)

Observed Well	Pumping or Recovery	Assumed Aquifer Thickness (ft)	Computed Transmissivity (ft^2/day)				Estimated Permeability (ft/day)				Computed Storativity/Specific Yield / gpm			
			Cooper-Jacob Method	Non-Leaky Aquifer using AQUITEST	Unconfined Aquifer using AQUITEST	Distance-Drawdown at 1400 min.	Cooper-Jacob Method	Non-Leaky Aquifer using AQUITEST	Unconfined Aquifer using AQUITEST	Distance-Drawdown at 1400 min.	Cooper-Jacob Method	Non-Leaky Aquifer using AQUITEST	Unconfined Aquifer using AQUITEST	Distance-Drawdown at 1400 min.
R-1	P	43	29.4	31.8	44.8	16.7	0.68	0.74	1.04	0.39	-	-	-	3.40E-03
	R	43	23.3	-	-	-	0.54	-	-	-	-	-	-	-
R-2	P	56	62.9	56.6	54.0	-	1.12	1.01	0.96	-	6.70E-04	9.40E-04	9.40E-04	-
													9.40E-03	-
R-3	P	49	-	48.1	64.7	-	-	0.98	1.32		-	8.10E-03	1.50E-02	-
													1.50E-01	-
MW-3	P	63	-	13.4	13.1	-	-	0.21	0.21	-	-	6.10E-03	6.90E-03	-
													6.90E-02	-
MW-7	P	50	-	305.0	20.7	-	-	6.10	0.41		-	6.00E-02	1.80E-02	-
													1.80E-01	-
MW-7D	P	50	34.4	41.8	50.2	-	0.69	0.84	1.00	-	6.00E-04	4.40E-04	2.80E-04	-
													2.80E-03	-
	R	50	22.5	-	-	-	0.45	-	-		-	-	-	-
MW-9	P	50	-	53.2	34.9	-	-	1.06	0.70			3.20E-02	3.50E-02	-
													3.50E-01	-
PUMPING TEST OF R-3 (3/24-25/88)														
R-3	P	50	48.4	49.5	56.7	239.0	0.97	0.99	1.13	4.78	-	-	-	1.80E-02
	R	50	54.6	-	-	-	1.09	-	-	-	-	-	-	-
R-2	P	50	-	37.7	204.0	-	-	0.75	4.08	-	-	1.70E-03	1.40E-02	-
													1.40E-01	
MW-3	P	50	-	46.2	28.6	-	-	0.92	0.57	-		7.10E-04	1.20E-03	
													1.20E-02	
MW-4	P	50	-	98.1	48.4	-	-	1.96	0.97	-		1.10E-02	1.00E-02	
													1.00E-01	
MW-4D	P	50	-	89.6	47.3	-	-	1.79	0.95	-	-	1.20E-02	9.80E-03	
													9.80E-02	
MW-8	P	50	-	81.7	81.7	-	-	1.63	1.63	-	-	2.60E-03	2.70E-03	
													2.70E-02	

RESULTS OF ANALYSIS OF PUMPING TESTS ON R-1 AND R-3 AT NJDOT FACILITY BASED ON DRAWDOWNS ADJUSTED FOR RISING TREND IN STATIC-WATER LEVEL WASHINGTON TOWNSHIP, MORRIS COUNTY

PUMPING TEST OF R-1 (3/27-28/98)

Observed Well	Pumping or Recovery	Assumed Aquifer Thickness (ft)	Computed Transmissivity (ft^2/day)				Computed Hydraulic Conductivity (ft/day)				Computed Storativity/Specific Yield			
			Cooper-Jacob Method	Non-Leaky Aquifer using AQUITEST	Unconfined Aquifer using AQUITEST	Distance-Drawdown at 1400 min.	Cooper-Jacob Method	Non-Leaky Aquifer using AQUITEST	Unconfined Aquifer using AQUITEST	Distance-Drawdown at 1400 min.	Cooper-Jacob Method	Non-Leaky Aquifer using AQUITEST	Unconfined Aquifer using AQUITEST	Distance-Drawdown at 1400 min.
R-1	P	43	29.4	31.8	44.8	16.7	0.68	0.74	1.04	0.39	*	*	*	3.40E-03
	R	43	21.3	-	-	-	0.54	-	-	-	*	*	*	-
R-2	P	56	62.9	56.6	54.0	-	1.12	1.01	0.96	-	6.70E-04	9.40E-04	9.40E-04	-
													9.40E-03	-
R-3	P	49	*	48.1	64.7	-	*	0.98	1.32	-	*	8.10E-03	1.50E-02	-
													1.50E-01	-
MW-3	P	63	*	13.4	13.1	-	*	0.21	0.21	-	*	6.10E-03	6.90E-03	-
													6.90E-02	-
MW-7	P	50	*	305.0	20.7	-	*	6.10	0.41	-	*	6.00E-02	1.80E-02	-
													1.80E-01	-
MW-7D	P	50	34.4	41.8	50.2	-	0.69	0.84	1.00	-	6.00E-04	4.40E-04	2.80E-04	-
													2.80E-03	-
	R	50	22.5	-	-	-	0.45	-	-	-	*	-	-	-
MW-9	P	50	*	53.2	34.9	-	*	1.06	0.70	-	*	3.20E-02	3.50E-02	-
													3.50E-01	-

PUMPING TEST OF R-3 (3/24-25/98)

R-3	P	50	48.4	49.5	56.7	239.0	0.97	0.99	1.13	4.78	*	*	*	1.80E-02
	R	50	54.6	-	-	-	1.09	-	-	-	*	*	*	-
R-2	P	50	*	37.7	204.0	-	*	0.75	4.08	-	*	1.70E-03	1.40E-02	-
													1.40E-01	
MW-3	P	50	*	46.2	28.6	-	*	0.92	0.57	-	*	7.10E-04	1.20E-03	-
													1.20E-02	
MW-4	P	50	*	98.1	48.4	-	*	1.96	0.97	-	*	1.10E-02	1.00E-02	-
													1.00E-01	
MW-4D	P	50	*	89.6	47.3	-	*	1.79	0.95	-	*	1.20E-02	9.80E-03	-
													9.80E-02	
MW-8	P	50	*	81.7	81.7	-	*	1.63	1.63	-	*	2.60E-03	2.70E-03	-
													2.70E-02	

NOTES: '-' Analysis not performed.

* Data do not conform to criteria for method

ESTIMATED WIDTHS OF CAPTURE ZONE WHEN PUMPING FROM A RECOVERY WELL FOR A RANGE OF DISCHARGE RATES, PERMEABILITY AND TIME OF PUMPING (ESTIMATED FROM PROGRAM BY CARL McELWEE OF KANSAS GEOLOGICAL SURVEY**) NJDOT HACKETTSTOWN FACILITY

		t = 100 days		t = 300 days	
Steady Well Discharge (gpm)	Horizontal Permeability (ft/day)	Capture Zone Width (in ft) at Well	Capture Zone Width (in ft) near MW-1	Capture Zone Width (in ft) at Well	Capture Zone Width (in ft) near MW-1
1.5	1.5	10	22.5	10	22.5
1.0	1.0	11	22.5	11.5	22.5
1.0	0.5	23.5	44.0	22.6	44.0
1.0	0.2	57	< 21	57.5	104.0
0.5	0.2	28.5	< 15	28.0	54.4

** *McElwee, Carl, 1990. Capture Zones for Simple Aquifers, Kansas Geological Survey, Computer Program Series #90-5.*

Appendix 5

Bushkill Member of the Martinsburg Formation (Upper Middle Ordovician)

Interbedded laminated to medium-bedded, dark-gray to black shale and slate, and less abundant laminated to thin-bedded, dark-gray to black siltstone. Complete Bouma (1962) turbidite sequences (Tabcde) are present, but basal cut-out sequences (Tcde and Tde) and are by far the most common and compose the bulk of the rock. Some beds contain sparse graptolites and brachiopods. Lower contact with the Jacksonburg Limestone is gradational, but commonly disrupted by thrust faulting. Parris and Cruikshank (1992) show that regionally this unit contains graptolites of the *Diplograptus multidens* to *Corynoides americanus* zones of Riva (1969, 1974), which they correlate to the *Climacograptus bicornis* zone to the *Corynoides americanus* subzone of the *Orthograptus amplexicaulis* zone of Berry (1960, 1971, 1976). Maximum thickness of unit in Musconetcong Valley is approximately 3,000 feet.

Jacksonburg Limestone (Middle Ordovician)

Laminated to thin-bedded, medium-dark- to dark-gray, shaly limestone with less abundant arenaceous limestone (cement rock facies). Grades downward into a fossiliferous, very thin to medium-bedded, interbedded mudstone, wackestone, and pebble-and-fossil packstone (cement limestone facies). Elsewhere, thick to very thick bedded dolomite cobble conglomerate occurs within the basal sequence. Lower contact is uncoonformable with the Beekmantown Group and the clastic facies of the locally occurring sequence at Wantage. Unit contains conodonts of the North American Midcontinent province, *Phragmodus undatus* to *Aphelognathus shatzeri* zones as used in Sweet and Bergstrom (1986), and so it is Rocklandian to Richmondian and possible Kirkfieldian (caradocian) (Karklins and Repetski, 1989). Unit is approximately 150 feet thick.

Sequence at Wantage (Middle Ordovician)

Interbedded very thin to medium-bedded limestone, dolomite, siltstone, and argillite. Upper carbonate facies, where present, is conformable with the Jacksonburg Limestone and grades downward into the clastic facies. The carbonate rocks are medium-bedded to laminated, medium- to dark-gray, very fine to fine-grained limestone and dolomite, and may have a very thin, moderate-yellowish-brown to olive-gray alteration rind. Rounded quartz sand may occur as floating grains and in very thin lenses. The clastic facies ranges from mudstone to siltstone with minor disseminated subangular to subrounded chert pebbles and medium-grained quartz sand. A coarse-grained quartz and white chert sandstone to pebbly conglomerate occurs in the Musconetcong Valley. Commonly thin- to medium-bedded. Some coarser-grained beds are cross stratified. Unit is restricted to lows on the Beekmantown unconformity surface. Based on identification of North American Midcontinent province conodonts within the carbonate facies, the unit age limit is Rocklandian-medial Shermanian and possible Kirkfieldian (Caradocian) (A. Harris, written commun., 1990). Unit ranges from 0 to approximately 150 feet thick.

Beekmantown Group

Very thin to thick-bed
Consists of three lith
fine- to medium-grain
olive-gray to dark-gra
Middle sequence is fi
laminae, and thin- to
grades laterally into fi
laminae. Grades dow
The dolomite is aphar
light-gray to light-blui
mottling, and is chara
olive-gray to grayish-
stone. Lower sequenc
ded, medium-grey to
to coarse-grained dolo
thin to thin, black che
toward the lower cont
conodonts of the Nort
proavis to *Rossodus*
Bergstrom (1986), so
unit is the Stonehenge
and the stonehenge F
Upper and middle seq
ewicz and Dalton (197
Formation of Markewi
600 feet thick.

OCa **Allentown Dolomite**

Very thin to very thick
The dolomite includes
An upper dolomite, at
fine- to medium-graine
is medium-dark- to me
two sequences of mec
quartzite and discontin
below the upper conta
sequence contains abu
grainstones, algal stro
Weathered exposures
dark-gray beds. Ripple
mud cracks, and paleo
shaly dolomite increas
Leithsville Formation.
Valley the lowest part
Dresbachian (Lower U
in the Musconetcong

Leithsville Formation

Thin-to thick-bedded
Dolomite in the upper
friable, mottled and m
sequence is thin- to m
medium gray. Shaly d
quartz sandstone, silts
abundant in the middl
quartz sand interbeds
Quartzite. Archaeocya
formation elsewhere in
disconformity so that
by the unit (Palmer an
Hyolithellus micans (M
approximately 800 fee

Beekmantown Group lower part (Lower Ordovician)

Very thin to thick-bedded interbedded dolomite and minor limestone. Consists of three lithologic sequences. Upper sequence is laminated, fine- to medium-grained dolomite, very thin to thick-bedded, light-olive-gray to dark-gray, at places weathers dark-yellowish-orange. Middle sequence is fine-grained dolomite having silty dolomite laminae, and thin- to medium-bedded, fine-grained limestone which grades laterally into fine-grained dolomite having silty dolomite laminae. Grades down into a fine-grained, laminated dolomite. The dolomite is aphanitic to fine-grained, dark-gray, weathers light-gray to light-bluish-gray, typically has dolomitic "reticulate" mottling, and is characterized by a pattern of anastomosing, light-olive-gray to grayish-orange laminae surrounding lenses of limestone. Lower sequence consists of thinly laminated to thick-bedded, medium-grey to medium-dark gray, locally mottled, aphanitic to coarse-grained dolomite having quartz sand laminae, local very thin to thin, black chert beds; slightly fetid. Quartz sand increase toward the lower contact. Lower contact gradational. Contains conodonts of the North American Midcontinent province *Cordylodus proavus* to *Rossodus manitouensis* zones, as used by Sweet and Bergstrom (1986), so unit is Ibexian (Tremadocian). Entire unit is the Stonehenge Limestone of Drake and others (1985) and the stonehenge Formation of Volkert and others (1989). Upper and middle sequences are the Epler Formation of Markewicz and Dalton (1977) and lower sequence is the Rickenbach Formation of Markewicz and Dalton (1977). Unit is about 600 feet thick.

Allentown Dolomite (Lowest Lower Ordovician to Upper Cambrian)

Very thin to very thick bedded, interbedded dolomite and shale. The dolomite includes minor interbeds of orthoquartzite and shale. An upper dolomite, at most places, is medium to very thick bedded, fine- to medium-grained, contains local coarse-grained beds, and is medium-dark- to medium-light-gray. Floating quartz sand and two sequences of medium light to very light gray, thin bedded quartzite and discontinuous dark gray chert lenses occur directly below the upper contact. A rhythmically bedded lower dolomite sequence contains abundant medium-to very light-gray-weathering grainstones, algal stromatolites, and light-gray weathering beds. Weathered exposures are characterized by alternating light and dark-gray beds. Ripple marks, cross beds, edgewise conglomerate, mud cracks, and paleosol zones occur in the lower unit. Interbedded shaly dolomite increases downward towards the lower contact with the Leithsville Formation. Lower contact conformable. In the Delaware Valley the lowest part of the unit contains a trilobite fauna of Dresbachian (Lower Upper Cambrian) age (Weller, 1903; Howell, 1945). In the Musconetcong Valley unit is approximately 1,900 feet thick.

Leithsville Formation (Middle to Lower Cambrian)

Thin-to thick-bedded dolomite containing subordinate clastic rocks. Dolomite in the upper part is massive, fine- to medium-grained, pitted, friable, mottled and medium- to medium-dark-gray. A lower dolomite sequence is thin- to medium-bedded, stylolitic, fine-grained, and medium gray. Shaly dolomite and clastic interbeds of varicolored quartz sandstone, siltstone, and shale occur throughout, but are most abundant in the middle of the unit. The lower dolomite sequence contains quartz sand interbeds near the lower contact with the Hardyston Quartzite. Archaeocyathids of Early Cambrian age occur in the formation elsewhere in New Jersey, suggesting an intraformational disconformity so that both Middle and Early Cambrian are represented by the unit (Palmer and Rozanov, 1976). Unit also contains Hyolithellus micans (Markewicz and Dalton, 1977). Thickness is approximately 800 feet in the Musconetcong Valley.

Medium-to
quartzite, ar
Elsewhere i
Olenellus th
Weller, 1903

Diabase dike

Medium-to d
dike south-s
sharp, confo
to slightly all
principally of
ilmeno-magn
similar to oth
Late Proteroz
thickness of

Byra

Hornblende g

Pinkish-gray
medium- to c
composed pri
hornblende, a
that is best e
not shown on
intercept U-P

Hornblende sy

Tan- to buff-w
grained to me
syenite contai
hornblende, a
monzodiorite.

Biotite granite

Pink- to buff-w
moderately fol
oligociase, biot

Microperthite

Pink- to buff-w
to coarse-grain
of microcline m
small bodies of

r part (Lower Ordovician)

nterbedded dolomite and minor limestone.
: sequences. Upper sequence is laminated,
)lomite, very thin to thick-bedded, light-
)laces weathers dark-yellowish-orange.
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ım-bedded, fine-grained limestone which
ained dolomite having silty dolomite
) a fine-grained, laminated dolomite.
o fine-grained, dark-gray, weathers
ay, typically has dolomitic "reticulate"
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e laminae surrounding lenses of lime-
nsists of thinly laminated to thick-bed-
ım-dark gray, locally mottled, aphanitic
having quartz sand laminae, local very
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Lower contact gradational. Contains
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nitouensis zones, as used by Sweet and

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id Dalton (1977). Unit is about

vest Lower Ordovician to Upper Cambrian)

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or interbeds of orthoquartzite and shale.
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s dark gray chert lenses occur directly
A rhythmically bedded lower dolomite
ant medium-to very light-gray-weathering
olites, and light-gray weathering beds.
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downward towards the lower contact with the
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ne, and shale occur throughout, but are most
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ar the lower contact with the Hardyston
ds of Early Cambrian age occur in the
ew Jersey, suggesting an intraformational
th Middle and Early Cambrian are represented
ozanov, 1976). Unit also contains
kewicz and Dalton, 1977). Thickness is
n the Musconetcong Valley.

Medium-to thick-bedded, fine-grained, medium- to lig
quartzite, arkosic sandstone and dolomitic sandstone.
Elsewhere in New Jersey contains fragments of the tr
Olenellus thompsoni of Early Cambrian age (Nason, 1
Weller, 1903). Maximum thickness of unit is 200 feet

New Jersey Highlands

Diabase dike (Late Proterozoic)

Medium-to dark-greenish-gray, fine-grained to aphanit
dike south-southeast of Scrappy Corner. Has chilled n
sharp, conformable contact with enclosing country ro
to slightly alkalic in composition, hypersthene normat
principally of labradorite to andesine, clinopyroxene (a
ilmeno-magnetite. Sparse pyrite blebs are ubiquitous.
similar to other Highlands diabase dikes that have bee
Late Proterozoic age by Volkert and Puffer (in press). I
thickness of dike is about 35 feet.

Byram Intrusive Suite of Drake (1984)

Hornblende granite (Middle Proterozoic)

Pinkish-gray to buff-weathering, pinkish-white or ligh
medium- to coarse-grained, gneissoid to indistinctly fo
composed principally of microcline microperthite, qua
hornblende, and magnetite. Locally incluses a pegmat
that is best exposed west of Pleasant Grove. Small ar
not shown on map are common whithin this unit. Gre
intercept U-Pb age of 1,090 Ma (Drake and others, 19

Hornblende syenite (Middle Proterozoic)

Tan- to buff-weathering, pinkish-gray or greenish-gray
grained to medium-coarse-grained, gneissoid syenite
syenite containing microcline microperthite, oligoclas
hornblende, and magnetite. Some phases of this unit
monzodiorite.

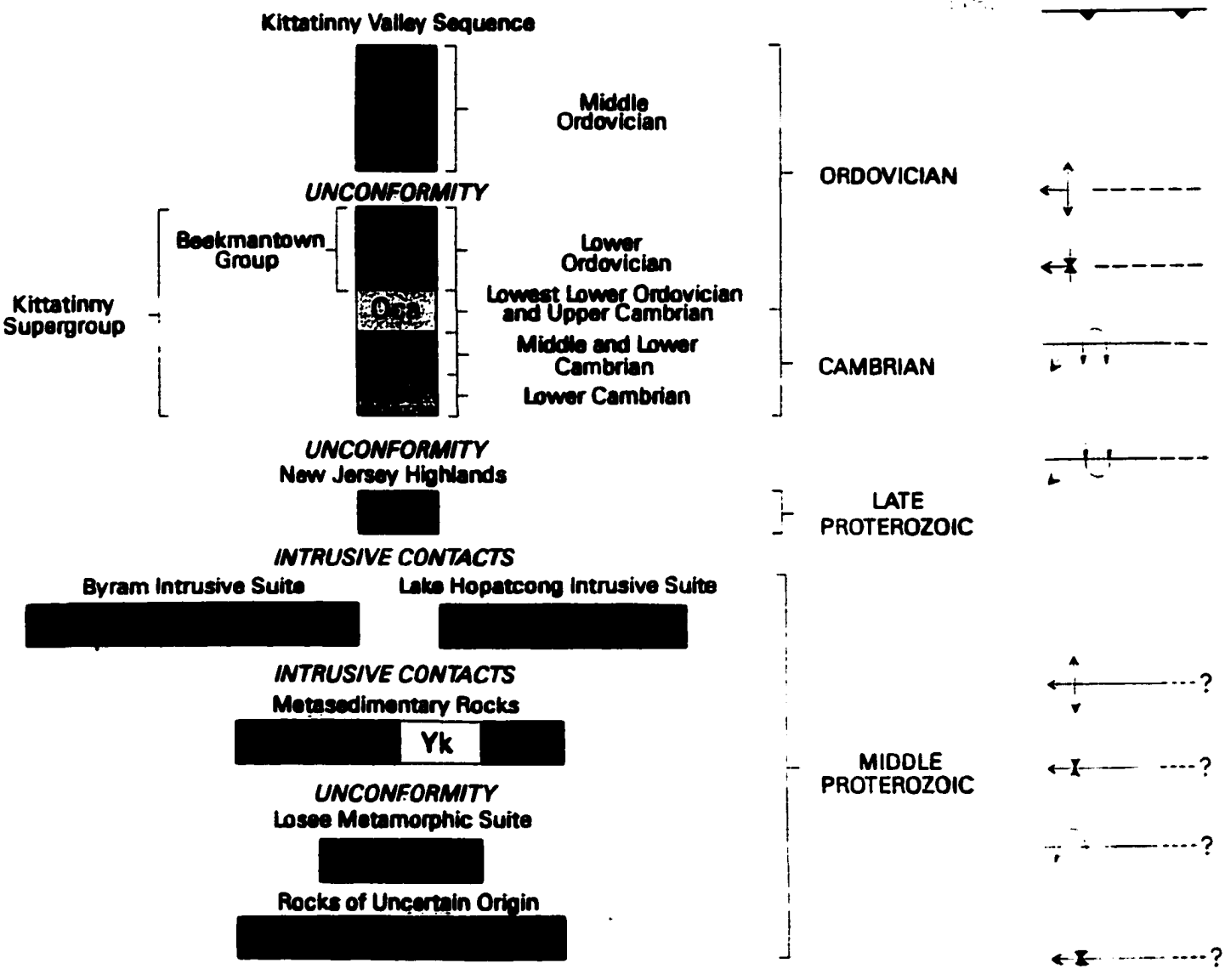
Biotite granite (Middle Proterozoic)

Pink- to buff-weathering, light-pinkish-gray, medium-g
moderately foliated granite composed of microcline m
oligoclase, biotite, and magnetite.

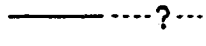
Microperthite alaskite (Middle Proterozoic)

Pink- to buff-weathering, light-pinkish-gray or pinkish-
to coarse-grained, gneissoid to indistinctly foliated gra
of microcline microperthite, quartz, oligoclase, and ma
small bodies of amphibolite not shown on map. Forme

CORRELATION OF MAP UNITS

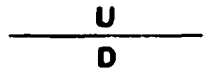


MAP SYMBOLS

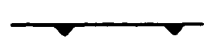


Contact - Dotted where concealed; queried where uncertain.

Faults - Dotted where concealed; queried where uncertain.



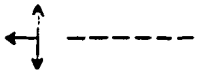
High angle fault - U, upthrown side; D, downthrown side



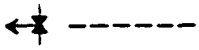
Thrust fault - Sawteeth on upper plate

FOLDS

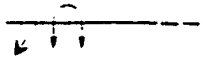
Folds in Middle Proterozoic rocks - in foliation and layering.



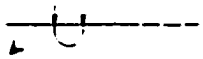
Antiform - Showing crestline and direction of plunge



Synform - Showing troughline and direction of plunge



Overturned antiform - Showing trace of axial surface, direction of dip of limbs, and direction of plunge



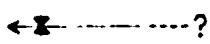
Overturned synform - Showing trace of axial surface, direction of dip of limbs, and direction of plunge

Folds in Paleozoic rocks - in bedding and cleavage. Dotted where concealed; queried where uncertain.

Anticline - Showing crestline and direction of plunge

Syncline - Showing troughline and direction of plunge

Syncline, gently inclined to recumbent - Showing trace of toughline, direction of dip of limbs, and direction of plunge



Cleavage trough - Showing troughline and direction of plunge

MINOR FOLDS

Minor fold axis - Showing bearing and plunge

Minor anticline or antiform - Showing bearing and plunge

MAP SYMBOLS

Contact - Dotted where concealed; queried where uncertain.

Faults - Dotted where concealed; queried where uncertain.

High angle fault - U, upthrown side; D, downthrown side

Thrust fault - Sawteeth on upper plate

FOLDS

Folds in Middle Proterozoic rocks - in foliation and layering.

Antiform - Showing crestline and direction of plunge

Synform - Showing troughline and direction of plunge

Overturned antiform - Showing trace of axial surface, direction of dip of limbs, and direction of plunge

Overturned synform - Showing trace of axial surface, direction of dip of limbs, and direction of plunge

Folds in Paleozoic rocks - in bedding and cleavage. Dotted where concealed; queried where uncertain.

Anticline - Showing crestline and direction of plunge

Syncline - Showing troughline and direction of plunge

Syncline, gently inclined to recumbent - Showing trace of toughline, direction of dip of limbs, and direction of plunge

Cleavage trough - Showing troughline and direction of plunge

MINOR FOLDS

Minor fold axis - Showing bearing and plunge

Minor anticline or antiform - Showing bearing and plunge

Strike and dip of beds - Dot indicates top of bed known from sedimentary features

Inclined

Vertical

Overturned

Strike and dip of crystallization foliation

Inclined

Vertical

Strike and dip of mylonitic foliation

Strike and dip of slaty cleavage

Strike and dip of parallel bedding and slaty cleavage

Strike and dip of spaced cleavage

Strike and dip of crenulation cleavage

LINEAR FEATURES

Bearing and plunge of mineral lineation in Proterozoic rocks

Bearing and plunge of intersection of bedding and slaty cleavage

Bearing and plunge of crenulation lineation

OTHER FEATURES

Abandoned limestone quarry

Abandoned magnetite mine

f

Fossil locality - where carbonate was sampled for conodonts to aid in identification of mation.

Drill hole - Bottoming in Jacksonburg Limes

Form line - Shown in cross section to indic foliation in Proterozoic rock

Beekmantown Group

Beekmantown Group upper part (Lower Ordovician)

Locally preserved, thin- to thick-bedded, aphanitic to medium-grained, medium-light- to medium-gray dolomite; weathers light- to medium-gray to yellowish-gray, locally laminated, slightly fetid. Grades downward into medium-to thick-bedded, medium- to coarse-grained, medium-dark- to dark-gray dolomite; strongly fetid, mottled weathered surface contains pods and lenses of dark-gray to black chert. Contains conodonts of the North American Midcontinent province *Rossodus manitouensis* zone through zone D, so unit is Ibexian (Tremadocian to Arenigian) as used by Sweet and Bergstrom (1986). In map area the unit includes the Rickenback Dolomite of Drake and others (1985) and is the Ontelaunee Formation of Markewicz and Dalton (1977). Thickness varies from 0 to 200 feet because of erosion on the Beekmantown unconformity.

Lake Hopatcong Intrusive Suite of Drake and Volkert (1991)

Pyroxene granite (Middle Proterozoic)

Gray- to buff- or white-weathering, greenish-gray, medi grained, gneissoid to indistinctly foliated granite conta to microantiperthite, quartz, oligoclase and clinopyroxe hornblende where unit is in contact with rocks of the L Suite. Some phases of this unit are quartz monzonite, and granodiorite. Locally contains small bodies of amp on map.

Pyroxene syenite (Middle Proterozoic)

Gray to buff or tan-weathering, greenish-gray, medium coarse-grained, gneissoid to indistinctly foliated syenit containing mesoperthite to microantiperthite, oligoclas and clinopyroxene. Contains accessory quartz, titanite magnetite, and trace amounts of pyrite.

Pyroxene alaskite (Middle Proterozoic)

Light-gray or tan-weathering, greenish-buff to light-gr -gray, medium- to coarse-grained, gneissoid to massive composed of mesoperthite to microantiperthite, oligoc quartz. Common accessories are clinopyroxene, titani magnetite. Locally contains small bodies of amphibolit shown on map.

Metasedimentary Rocks

Biotite-quartz-feldspar gneiss (Middle Proterozoic)

Biotite-quartz-feldspar gneiss (Middle Proterozoic) Gra locally rusty, pinkish-gray, tan, or greenish-gray, mediu medium-coarse-grained, moderately layered and foliat is variable in texture and composition. Composed of cl microperthite, quartz, and biotite. Locally contains gar sillimanite, and opaque minerals.

Quartzite (Middle Proterozoic)

Light-gray to grayish-buff, medium-grained, well-layer feldspathic quartzite. Contains sparse granite. Assoc quartz-feldspar gneiss (Yb) and potassic feldspar gnei

Yk

Potassic feldspar gneiss (Middle Proterozoic)

Light-gray-to pinkish-buff-weathering, pinkish-white t medium-fine to medium-grained, moderately foliated t lesser granofels composed of quartz, microcline, micr oligoclase, and local accessory biotite, garnet, and ma of Drakestown, unit contains thin interlayers of feldsp with locally abundant magnetite.

Appendix 6

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-1	MW-1	MW-1	MW-1	MW-1	MW-1	MW-1	MW-1	MW-1	MW-2	MW-2	MW-2	MW-2
Date:		09/12/96	03/21/97	05/07/97	06/17/97	10/01/97	04/10/98	07/10/98	04/09/99	07/15/99	09/12/96	03/21/97	05/07/97	06/17/97
Parameter	Units													
Temperature	Degrees Celcius	11.9	12.8	13.1	14.7	15.0	12.7	15.1	13.3	22.8	13.8	12.9	11.7	15.4
pH	Standard Units	6.12	5.64	7.87	6.95	5.90	7.02	5.60	9.86	--	7.23	6.02	7.87	7.39
Conductivity	MicroSiemens	140	1.02	3.45	470	0.14	1.02	2.51	1.54	1.32	160	1.91	1.98	112
Dissolved Oxygen	ppm	2.90	2.28	2.25	14.60	9.80	10.34	2.08	2.04	12.56	0.94	1.35	2.56	2.77
ORP	mV	56	154	--	113	86	191	210	170	131	35	-099	-103	28

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-2	MW-2	MW-2	MW-3*	MW-3	MW-3	MW-3	MW-3	MW-3	MW-4	MW-4	MW-4	MW-4
Date:		04/10/98	07/10/98	07/15/99	09/12/96	03/20/97	05/07/97	06/17/97	04/08/98	07/07/98	03/21/97	05/07/97	06/17/97	04/10/98
Parameter	Units													
Temperature	Degrees Celcius	11.5	16.0	19.8	12.7	10.4	9.9	13.6	17.4	13.7	13.2	13.5	13.2	13.9
pH	Standard Units	6.45	6.90	--	7.20	5.59	7.41	6.69	6.72	6.47	6.03	7.66	7.44	6.67
Conductivity	MicroSiemens	2.32	4.30	4.28	310	12.0	10.8	608	14.0	13.7	2.91	2.72	1440	0.665
Dissolved Oxygen	ppm	9.77	2.12	13.01	2.09	2.74	4.86	2.59	9.58	2.20	2.96	1.81	4.50	11.64
ORP	mV	172	65	120	--	314	19	128	152	128	-015	12	76	190

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-4	MW-4	MW-4	MW-4D	MW-4D	MW-4D	MW-4D	MW-4D	MW-4D	MW-4D	MW-4D	MW-4D	MW-5
Date:		07/10/98	04/07/99	07/15/99	06/20/97	10/01/97	01/08/98	04/10/98	07/10/98	10/01/98	01/13/99	04/08/99	07/15/99	03/20/97
Parameter	Units													
Temperature	Degrees Celcius	14.4	14.0	20.1	15.8	13.1	13.4	11.6	14.3	15.1	9.1	16.2	20.1	9.2
pH	Standard Units	6.66	7.97	--	6.56	6.47	6.31	6.85	6.91	7.06	7.80	8.45	--	5.38
Conductivity	MicroSiemens	5.33	2.62	3.01	--	0.70	0.83	1.51	4.30	1.84	2.31	1.92	2.04	0.541
Dissolved Oxygen	ppm	16.48	4.10	4.07	3.22	4.20	4.08	9.85	5.36	13.26	9.20	3.96	10.33	4.55
ORP	mV	204	--	102	126	78	213	121	195	245	350	-080	112	262

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-5	MW-5	MW-5	MW-5	MW-5	MW-6	MW-6	MW-6	MW-6	MW-6	MW-7	MW-7	MW-7
Date:		05/06/97	06/17/97	04/07/98	07/07/98	07/14/99	03/20/97	05/07/97	06/17/97	04/08/98	07/09/98	03/20/97	05/07/97	06/17/97
Parameter	Units													
Temperature	Degrees Celcius	13.9	13.0	17.7	16.0	19.2	11.2	10.9	15.5	17.8	15.6	10.9	12.8	15.7
pH	Standard Units	7.45	7.66	6.11	5.79	--	5.88	7.94	6.86	6.53	6.72	5.77	7.74	6.44
Conductivity	MicroSiemens	5.57	190	2.26	1.29	0.598	3.53	2.05	2940	3.17	5.71	3.67	5.10	7730
Dissolved Oxygen	ppm	11.57	7.80	9.04	1.98	18.77	1.54	4.62	2.23	8.59	14.70	2.42	2.48	2.56
ORP	mV	43	101	-040	97	133	233	28	107	-073	168	322	34	125

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-7	MW-7D	MW-7D	MW-7D	MW-7D	MW-7D*	MW-7D	MW-7D	MW-8	MW-8	MW-8	MW-8	MW-8
Date:		07/09/98	06/20/97	10/01/97	07/09/98	08/07/98	10/08/98	01/20/99	04/08/99	06/20/97	10/01/97	04/08/98	07/09/98	04/07/99
Parameter	Units													
Temperature	Degrees Celcius	14.8	14.8	14.2	14.4	25.6	12.2	10.1	12.8	14.0	14.0	17.8	13.3	15.7
pH	Standard Units	6.65	6.49	6.15	7.41	6.01	6.12	5.43	9.28	6.46	5.90	7.28	6.71	7.37
Conductivity	MicroSiemens	15.50	--	6.30	14.80	0.912	14.0	10.0	6.6	--	2.30	2.04	3.97	2.64
Dissolved Oxygen	ppm	2.27	1.39	3.52	11.72	6.16	3.39	9.14	9.09	4.03	2.40	8.87	4.31	5.68
ORP	mV	165	-084	54	-013	193	193	--	--	137	78	103	142	202

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-8	MW-9	MW-9	MW-9	MW-10	MW-10	MW-10	MW-10	MW-10	MW-10	MW-10	MW-10	MW-10
Date:		07/13/99	06/20/97	04/08/98	07/09/98	09/29/97	01/07/98	04/07/98	07/08/98	08/07/98	10/07/98	01/13/99	04/07/99	07/13/99
Parameter	Units													
Temperature	*Degrees Celcius*	18.3	16.4	15.6	16.4	14.5	12.2	14.9	15.0	25.4	12.3	10.8	11.4	15.6
pH	Standard Units	3.95	5.78	5.93	6.41	5.94	5.29	6.18	7.47	6.47	6.29	6.62	6.93	6.85
Conductivity	MicroSiemens	2.63	--	6.73	18.71	1.42	2.30	1.31	0.775	0.472	3.46	4.50	1.92	1.91
Dissolved Oxygen	ppm	19.99	3.27	9.61	14.05	15.07	14.1	10.12	6.40	8.02	10.96	10.20	7.56	19.99
ORP	mV	169	151	113	210	80	127	-080	162	200	230	--	218	129

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		MW-11	MW-11	MW-11	MW-11	MW-11	MW-12	MW-12	MW-12	MW-12	MW-12	PR-1	PR-4	PR-4
Date:		09/30/97	04/06/98	07/08/98	10/06/98	07/13/99	09/30/97	04/06/98	07/07/98	10/06/98	07/13/99	01/08/98	10/01/98	01/13/99
Parameter	Units													
Temperature	Degrees Celcius	13.1	14.8	15.1	13.5	14.1	13.2	15.1	12.3	14.1	13.6	13.5	16.8	9.2
pH	Standard Units	5.98	7.28	6.45	5.72	6.81	6.18	7.43	6.54	6.34	7.22	6.14	7.01	7.40
Conductivity	MicroSiemens	0.319	0.028	0.442	0.794	0.505	0.268	0.297	0.631	0.311	0.479	2.49	2.09	1.90
Dissolved Oxygen	ppm	16.93	9.63	7.11	10.51	19.99	10.14	9.87	6.15	10.11	9.82	5.36	10.98	9.80
ORP	mV	71	77	69	191	168	64	-091	106	184	197	237	262	330

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

APPENDIX 6
WATER QUALITY PARAMETERS
COLLECTED DURING GROUNDWATER SAMPLING
NJDOT-HACKETTSTOWN MAINTENANCE FACILITY
WASHINGTON TOWNSHIP, NEW JERSEY

Location:		R-1	R-1*	R-1	R-1	R-2	R-2	R-2*	R-2	R-2	R-2	R-3	R-3*
Date:		07/09/98	10/08/98	04/08/99	07/14/99	04/07/98	07/09/98	10/08/98	01/20/99	04/08/99	07/14/99	07/09/98	10/08/98
Parameter	Units												
Temperature	Degrees Celcius	15.1	12.3	13.0	14.8	17.2	14.9	12.0	10.3	12.5	14.0	14.9	11.9
pH	Standard Units	6.80	6.19	7.80	3.93	6.29	6.76	6.17	5.13	9.11	3.76	6.83	6.50
Conductivity	MicroSiemens	15.1	17.7	6.94	6.44	3.70	15.3	7.81	6.16	3.55	3.11	5.77	3.47
Dissolved Oxygen	ppm	7.20	9.59	4.80	14.40	9.69	2.39	0.23	11.11	12.85	8.80	12.48	4.74
ORP	mV	134	199	--	100	-037	52	151	--	--	101	121	178

Notes:

ppm	parts per million
ORP	oxidation-reduction potential
mV	millivolts
--	field measurement not taken
*	field measurements taken during well pumping
PR	product recovery well
R	recovery well
MW	monitoring well

Appendix 7

Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-1	MW-1	MW-1	MW-1	MW-1	MW-1
Sampling Date:		09/12/96	03/21/97	05/07/97	05/07/97	06/17/97	10/01/97
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	7,400	2,700	150	2,200	1,600	1,900
Chloromethane	30	1,100	11.5 U	2.3 U	230	11.5	230
Methyl tertiary butyl ether (MTBE)	70	29,900	200	80	250	110	3,800
Toluene	1,000	29,700	8,900	5.0	26,000	25,200	36,000

See footnotes on last page

Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-1	MW-1	MW-2	MW-2 Replicate MW-4	MW-2	MW-2
Sampling Date:		04/10/98	07/10/98	09/12/96	09/12/96	03/21/97	05/07/97
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	1,300	280	3,200	2,800	3,800	2,600
Chloromethane	30	460 U	93	110	570	180	2.3
Methyl tertiary butyl ether (MTBE)	70	500 U	100	73,500	84,400	30,000	11,800
Toluene	1,000	21,000	11,000	1,700	1,700	4,500	4,400

See footnotes on last page

Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-2	MW-2	MW-2	MW-2	MW-3	MW-3
Sampling Date:		05/07/97	06/17/97	04/10/98	07/10/98	09/12/96	03/20/97
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	3,000	4,000	220	2,900	R	70
Chloromethane	30	230	180	1.9	46	R	2.3
Methyl tertiary butyl ether (MTBE)	70	15,000	27,300	500	4,800	R	1,200
Toluene	1,000	4,900	5,400	610	3,300	R	3.3

See footnotes on last page

Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-3	MW-3	MW-3	MW-3	MW-3	MW-4
Sampling Date:		05/07/97	05/07/97	06/17/97	04/08/98	07/07/98	03/21/97
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	0.6	0.2	7.3	0.4	17	6,000
Chloromethane	30	2.3	0.9	2.3	0.9	0.9	11 5
Methyl tertiary butyl ether (MTBE)	70	23	31	260	2.3	66	50,300
Toluene	1,000	0.5	0.2	0.5	0.2	16	7,700

See footnotes on last page

Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-4	MW-4	MW-4	MW-4 Replicate	MW-4	MW-4
Sampling Date:		05/07/97	05/07/97	06/17/97	REP061797 06/17/97	04/10/98	07/10/98
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	5,900	8,000	3,000	3,500	170	2,500
Chloromethane	30	2.3	230	11.5	11.5	1.9	23
Methyl tertiary butyl ether (MTBE)	70	25,400	36,000	7,900	9,000	320	4,600
Toluene	1,000	11,400	15,000	6,200	6,900	340	2,900

See footnotes on last page

Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-4	MW-4D	MW-4D	MW-4D	MW-4D	MW-4D
Sampling Date:		04/08/99	06/20/97	10/01/97	01/08/98	04/10/98	07/10/98
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	2,300	11	1,200	1,900	2,900	2,300
Chloromethane	30	--	11	19	46	93	19
Methyl tertiary butyl ether (MTBE)	70	5600	7,700	7,300	5,700	8,000	4,000
Toluene	1,000	2200	1,300	100	720	3,200	1,200

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-4D	MW-4D Replicate REP100198	MW-4D	MW-5	MW-5	MW-5
Sampling Date:		10/01/98	10/01/98	01/14/99	03/20/97	05/06/97	05/06/97
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	1,100	770	360	0.6	0.6	0.2
Chloromethane	30	9.3	19	4.6	2.3	2.3	0.9
Methyl tertiary butyl ether (MTBE)	70	2,000	1,800	390	5.0	5.0	1.0
Toluene	1,000	710	460	150	0.5	0.5	0.2

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-5	MW-5	MW-5	MW-5 Replicate	MW-6	MW-6
Sampling Date:		06/17/97	04/07/98	07/07/98	REP070798 07/07/98	03/20/97	05/07/97
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	0.6	0.2	0.2	0.2	2,900	540
Chloromethane	30	2.3	0.9	0.9	0.9	230	2.3
Methyl tertiary butyl ether (MTBE)	70	4.9	5.0	3.7	3.7	71,000	2,600
Toluene	1,000	0.5	0.5	0.2	0.2	1,500	260

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-6 Replicate REP050797	MW-6	MW-6	MW-6	MW-6	MW-7
Sampling Date:		05/07/97	05/07/97	06/17/97	04/08/98	07/09/98	03/20/97
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	300	500	3,000	21	690	3,900
Chloromethane	30	2.3	23	11.5	1.9	19	2.3
Methyl tertiary butyl ether (MTBE)	70	2,200	3,800	31,900	440	2,500	49,200
Toluene	1,000	140	130	250	0.4	620	880

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-7 Replicate REP032097	MW-7	MW-7	MW-7	MW-7	MW-7D
Sampling Date:		03/20/97	05/07/97	05/07/97	06/17/97	07/09/98	06/20/97
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	5,700	R	3,200	1,200	2,000	35
Chloromethane	30	2.3	110	460	11.5	190	35
Methyl tertiary butyl ether (MTBE)	70	57,100	44,100	63,000	25,700 D	24,000	2,800
Toluene	1,000	10,800	170	250	100	220	0.5

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-7D(062697)	MW-7D(062797)	MW-7D	MW-7D Replicate	MW-7D	MW-7D
Sampling Date:		06/26/97	06/27/97	10/01/97	REP100197 10/01/97	04/10/98	07/09/98
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	160	130	320	300	150	110
Chloromethane	30	2.3	2.3	9.3	9.3	93	23
Methyl tertiary butyl ether (MTBE)	70	4,400	3,800	4,100	3,800	7,100	2,700
Toluene	1,000	11	7.4	3.2	3.3	18	54

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-7D	MW-7Dins*	MW-7D	MW-7D	MW-8	MW-8
Sampling Date:		08/07/98	10/08/98	01/20/99	04/08/99	06/20/97	10/01/97
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	140	38	48	25	2	290
Chloromethane	30	23	9.3	46	--	2	9.3
Methyl tertiary butyl ether (MTBE)	70	3,100	1,600	4,100	5000	700	4,400
Toluene	1,000	4.5	1.8	9	2.6	0.5	11

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-8	MW-8	MW-8 Replicate	MW-8	MW-9	MW-9
Sampling Date:		04/08/98	07/09/98	REP070998 07/09/98	04/07/99	06/20/97	04/08/98
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	0.8	0.2	0.2	0.3	2	0.2
Chloromethane	30	0.9	0.9	0.9 U	–	2	0.9
Methyl tertiary butyl ether (MTBE)	70	89	15	15	24	250	47
Toluene	1,000	0.2	0.2	0.2	0.3	0.5	0.2

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-9	MW-10	MW-10	MW-10	MW-10 Replicate	MW-10
Sampling Date:		07/09/98	09/09/97	09/29/97	01/07/98	REP010798 01/07/98	04/07/98
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	0.2	0.2	0.2	0.2	0.2	0.2
Chloromethane	30	0.9	0.9	0.9	0.9	0.9	0.9
Methyl tertiary butyl ether (MTBE)	70	2.8	20	17.6	29	28	23
Toluene	1,000	0.2	0.2	0.2	0.2	0.2	0.2

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1998 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-10	MW-10	MW-10	MW-10 Replicate REP100798	MW-10	MW-10 Replicate REP011399
Sampling Date:		07/08/98	08/07/98	10/07/98	10/07/98	01/13/99	01/13/99
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	0.2	0.2	0.2	0.2	0.2	0.5
Chloromethane	30	0.9	--	0.9	0.9	0.9	1.9
Methyl tertiary butyl ether (MTBE)	70	1.4	3.8	8.3	9.4	21	670
Toluene	1,000	0.2	--	0.2	0.2	0.2	0.4

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-10	MW-10 Replicate	MW-11	MW-11	MW-11	MW-11
Sampling Date:		04/07/99	REP040799 04/07/99	09/09/97	09/30/97	04/06/98	07/08/98
Units:	NJDEP Groundwater Quality Criteria ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Benzene	1	0.3	0.3	0.2	0.2	0.2	0.2
Chloromethane	30	--	--	0.9	0.9	0.9	0.9
Methyl tertiary butyl ether (MTBE)	70	19	25	15	16	19	21
Toluene	1,000	0.3	0.3	0.2	0.2	0.2	0.2

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		MW-11	MW-12	MW-12	MW-12	MW-12	MW-12
Sampling Date:		10/06/98	09/09/97	09/30/97	04/06/98	07/07/98	10/06/98
Units:		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L						
Benzene	1	0.2	0.2	0.2	0.2	0.2	0.2
Chloromethane	30	0.9	0.9	0.9	0.9	0.9	0.9
Methyl tertiary butyl ether (MTBE)	70	8.7	1.0	1.0	1.0	1.0	1.0
Toluene	1,000	0.2	0.2	0.2	0.2	0.2	0.2

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

Sample Name:		R-1	R-2	R-3
Sampling Date:		04/08/99	04/08/99	04/08/99
Units:		ug/L	ug/L	ug/L
	NJDEP Groundwater Quality Criteria ug/L			
Benzene	1	28	68	71
Chloromethane	30	--	--	--
Methyl tertiary butyl ether (MTBE)	70	3,000	7,000	2,000
Toluene	1,000	1.3	5.2	1.3

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Appendix 7
Concentrations of Volatile Organic Compounds in Groundwater,
September 1996 through April 1999
NJDOT-Hackettstown Maintenance Facility,
Washington Township, New Jersey

NJDEP		New Jersey Department of Environmental Protection.
ug/L	Sample N	Micrograms per liter, equivalent to parts per billion.
R		Analysis rejected, compound presence is not verifiable.
–		Parameter not analyzed by laboratory.
MW		Monitoring Well
R-1		Recovery Well 1

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