GROUNDWATER IMPACT STUDY

SUMMARY REPORT

Prepared for

INLAND FISHER GUIDE
GENERAL MOTORS CORPORATION
1445 Parkway Avenue
Trenton, New Jersey

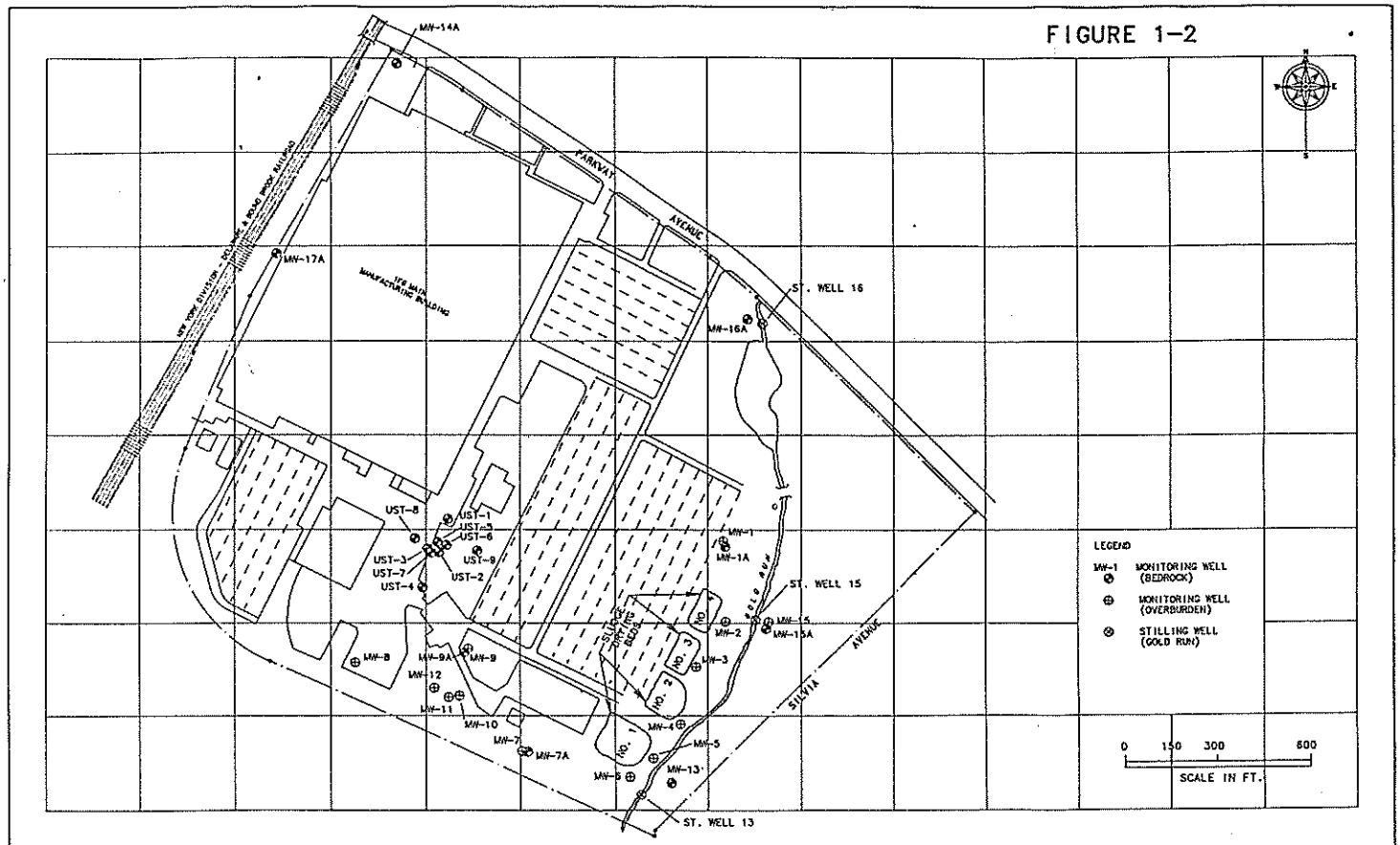
May 1991

Prepared by

LAWLER, MATUSKY & SKELLY ENGINEERS
Environmental Science & Engineering Consultants
One Blue Hill Plaza
Pearl River, New York 10965

Project No. 498-007

FIGURE 1-2



	PREPARED BY: LAWLER, MATUSKY & SKELLY ENGINEERS, ENVIRONMENTAL SCIENCE AND ENGINEERING CONSULTANTS, ONE BLUE HILL PLAZA, PEARL RIVER, NY 10965	FOR: INLAND FISHER GUIDE, TRENTON, NEW JERSEY	PLOT PLAN, MON. WELLS & STREAM LOCATIONS, SCALE: 1" = 300 FT.	DATE: JUL. 30, 1991; DWG. NO. 498007

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CHAPTER 1

INTRODUCTION

Lawler, Matusky & Skelly Engineers (LMS) was retained by the Inland Fisher Guide (IFG) Division of General Motors (GM) in October 1990 to provide technical services related to the ongoing Groundwater Impact Study of their Trenton, New Jersey, facility (Figure 1-1). This report provides a summary of LMS' observations and interpretations based on the completion of the field and analytical activities authorized by IFG over the course of this project. LMS' field activities included (1) the installation of four additional groundwater monitor wells, (2) sampling of 23 monitor wells associated with IFG's quarterly groundwater monitoring program (including the four new wells), and (3) the collection of continuous water level measurements from three pairs of Stevens recorders installed at adjacent monitor well/stream locations. LMS' analytical work has focused on the review and interpretation of the available information concerning the geology and hydrogeology of the IFG-Trenton site, as well IFG's recent and historical groundwater and surface water quality data.

This project was initiated on 3 October 1990 at a meeting of representatives of IFG, LMS, and New Jersey Department of Environmental Protection (NJDEP) Division of Water Resources. Major issues discussed with Erik Kinsel of NJDEP at this meeting included:

- The potential impact of an upgradient facility (Naval Air Propulsion Research Center) on the groundwater quality observed at IFG.
- The final locations for the installation of four additional monitor wells on IFG's property to address the potential upgradient influence on groundwater quality.
- The potential preferred conduit of contaminant migration represented by Gold Run, as well as this surface water stream's influence on local groundwater flow and contaminant migration.
- The use of a comprehensive database on IFG's groundwater quality to help determine (a) target parameters and/or wells for future monitoring and (b) the conceptual approach to the remediation of groundwater problems associated with IFG's operations.

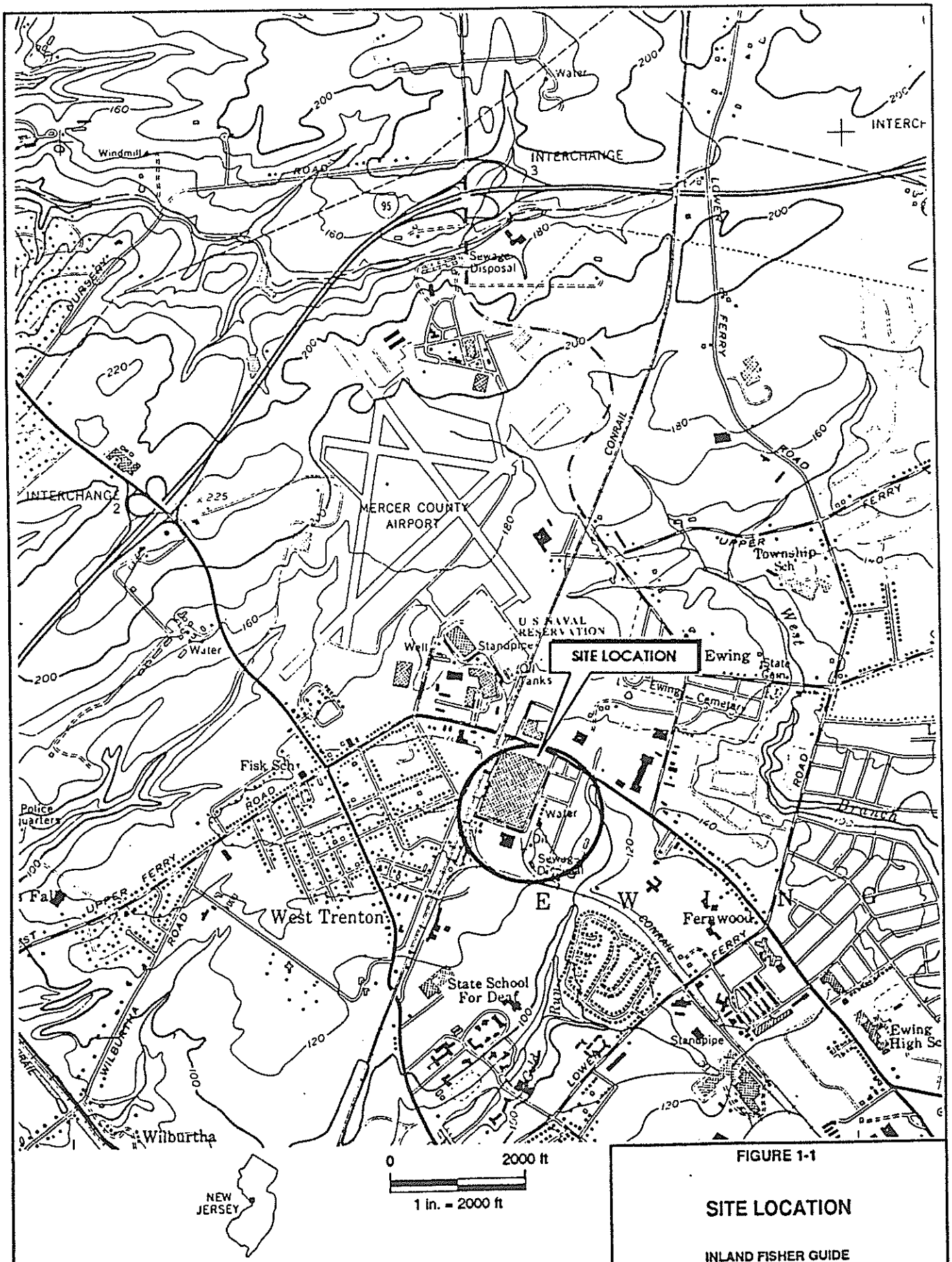
These issues, as well as several other technical issues raised by LMS during the course of this project, are discussed in greater detail in the sections that follow.

1.1 BACKGROUND

IFG's Trenton facility is located at 1445 Parkway Avenue in Ewing Township, a suburb of Trenton, New Jersey (Figure 1-1). The groundwater monitoring program at IFG-Trenton was initiated in 1986 with the installation and sampling of 12 monitor wells located both upgradient and downgradient of four inactive sludge-drying impoundments (Figure 1-2). This program was required by IFG's New Jersey Pollutant Discharge Elimination System (NJPDES) Discharge to Groundwater (DGW) permit number NJ0053295 administered under *N.J.A.C. 7:14-1 et seq.* IFG's NJPDES/DGW permit was revised in March 1990 and reissued as permit number NJ0075469. The original NJPDES permit number (NJ0053295) remains in effect for IFG's surface water and SIU discharges.

IFG's ongoing NJPDES/DGW groundwater monitoring program to date has involved the installation of 21 overburden and bedrock monitor wells. Nine additional monitor wells have been installed as part of a separate groundwater investigation associated with a former underground storage tank (UST). In addition to the 21 NJPDES/DGW wells mentioned above, IFG's current quarterly groundwater sampling program includes two of the UST wells. A third UST well, UST-5, is proposed for inclusion in future DGW sampling events. A summary of the 24 groundwater monitor wells included (and/or proposed for inclusion) in IFG's quarterly sampling program, (along with relevant technical information concerning their location and construction), is provided in Table 1-1.

IFG's groundwater monitoring program follows the technical directions set forth in their NJPDES/DGW permit, which references the Federal guidelines promulgated by *40CFR Part 136 (Guidelines Establishing Test Procedures for the Analysis of Pollutants)* and pertinent New Jersey regulations. These regulations provide general guidance for the management of the technical components of environmental sampling and characterization projects such as IFG's groundwater investigation, including well development procedures, equipment and methodology used for sample collection, sample preparation and shipment procedures, and



Map source: USGS Quadrangle Map, Pennington, NJ, 1954 (Photorevised 1981)

FIGURE 1-1

SITE LOCATION

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parameters and laboratory methods for chemical analysis. The site-specific elements of IFG's groundwater monitoring program have been identified and approved in previous communications between IFG and NJDEP.

1.2 SITE HISTORY

The following summary of the GM Trenton Plant's historical operations was provided to LMS by IFG-Trenton personnel.

The GM Trenton Plant was constructed in 1937 and started manufacturing operations for the old Ternstedt Division in 1938. The plant produced one product, automotive window regulators for Fisher Body. Manufacturing operations included metal stamping and fabrication. In 1942 the Trenton Plant stopped all automotive hardware production when for wartime purposes five area GM plants were recast into Eastern Aircraft Corporation. The plant retooled and produced 7546 Avenger Torpedo Bombers during World War II.

After the conclusion of World War II, the plant was returned to the Ternstedt Division. The manufacturing operations were expanded to include window regulators, door handles, seat adjusters, and vent windows. Processes included metal stamping, plating (copper, nickel, and chrome), and painting operations.

The Ternstedt Division was merged into Fisher Body in 1968. Manufacturing operations were expanded to include aluminum anodizing and plastic injection molding. Additional painting operations were added to paint plastic products, aluminum products, and seat adjuster components.

In 1970 there was a major production shift with the design elimination of the automobile's vent window. The loss of the vent window eliminated half of the zinc die cast operations, which resulted in the subsequent closure of several of the platers. The available floor space was filled with PVC plastic extruders used to manufacture body side moldings.

In 1976 aluminum fabrication and anodizing were consolidated by Fisher Body; these components of the Trenton Plant's operations were transferred to the Columbus, Ohio, plant. Consequently, Trenton's aluminum anodizer and associated paint area were shut down. Encapsulated glass operations were assigned to the manufacturing floor space.

Fisher Body was merged with the Guide Lamp division of GM to form Fisher Guide in 1984. Subsequently, the electrostatic paint operation was shut down in 1988 as a result of the designed phase-out of the interior paint moldings operation. An *ELPO* primer and powder paint operation replaced the former electrostatic paint operation. The *ELPO* primer operations involved the electrophoretic deposition of a nonhazardous water-based paint primer on automotive body parts. The most recent addition to the Trenton Plant's manufacturing processes is the bilaminate roll form and extrusion process. This process consists of an aluminim or stainless steel sheet being roll formed and coated with PVC in one operation. The bilaminate roll form and extrusion process was initiated in 1986 and continues to this day.

Fisher Guide was merged with the Inland division of GM to form Inland Fisher Guide (IFG) in 1989. No major changes to plant operations occurred as a result.

The process wastewaters generated from IFG's historical painting and plating operations were treated at their on-site wastewater treatment facility. The constituents of these waste streams that were not degraded or destroyed became incorporated into the sludges generated at the wastewater treatment facility, which were ultimately disposed of off-site after being dewatered in the four former sludge impoundments shown on Figure 1-2. Closure of the four former slugde impoundments were conducted from 1973 to 1974. The colosure procedure consisted of emplacement of non-hazardous construction and demolition (C&D) debris in each impoundment to at or near grade, leveling of the impoundments' side walls, (which were constructed of native soils), and the emplacment of a final cover of C&D fill material. Sludges that were present in the former impoundments at the time of closure were not removed.

A summary of IFG's historical solvent usage associated with each of the processes cited above is provided in Appendix A. In addition, a summary of the compounds associated with the generation and disposition of the waste streams from these processes is also included in Appendix A. Laboratory data on the chemical composition of the sludge contained in the impoundments are provided separately in Appendix B.

1.3 GROUNDWATER ISSUES

LMS has reviewed the operational history of the IFG-Trenton facility, IFG's historical groundwater data, and the available information on the Naval Air Propulsion Center upgradient of IFG. LMS' review of this information has suggested that the groundwater problems identified in the vicinity of IFG can be evaluated as separate issues. Therefore, this report will address three separate groundwater issues in terms of their probable source areas and principal contaminants. These issues are summarized below:

GROUNDWATER ISSUE	PROBABLE SOURCE AREA	PRINCIPLE CONTAMINANTS
(1) UST area	Former 4000-gal gasoline UST (IFG)	Light petroleum hydrocarbons, including benzene, toluene, and xylene (BTX), and lead (Pb).
(2) Sludge impoundment area	Four inactive sludge-drying impoundments (IFG)	Trichlorobenzenes, dichloro-benzenes, chlorobenzene, 1,1,1-trichloroethane (TCA) and 1,1-DCA, certain metals (including As, Cd, Zn, Cu, and Ni), and semi-volatile compounds.
(3) Background (upgradient) conditions	Naval Air Propulsion Center (directly across Parkway Avenue from IFG)	Trichloroethylene (TCE) and degradation products (e.g., 1,2-trans-DCE and vinyl chloride). Certain semivolatile compounds and metals are also likely.

These issues are discussed in greater detail in the sections that follow.

1.3.1 Underground Storage Tank (UST) Area

Since 1987 IFG has retained LMS and other consultants for the investigation of soil and groundwater contamination associated with a former 4000-gal gasoline underground storage

tank (UST). The UST was promptly removed from service, excavated, and removed in 1987 (Weston 1988a). The UST was a former component of IFG's industrial wastewater system, and was located in the south-central area of the site (Figure 1-2).

IFG has managed the UST groundwater investigation separately from that being conducted under their current NJPDES/DGW permit. The UST area groundwater investigation has been administered by IFG under the direct oversight of Mr. Erik Kinsel of NJDEP-Division of Water Resources. Consequently, the nine groundwater monitor wells associated with the UST area are identified with the prefix UST-, (e.g., UST-1 through UST-9; Figure 1-2). As previously mentioned, only two of the nine UST wells (UST-7 and UST-8), have ever been included in previous rounds of IFG's NJPDES/DGW quarterly groundwater sampling (Table 1-1). A third UST monitor well, UST-5, is proposed for inclusion in future quarterly sampling events (Table 1-1).

The principal contaminants observed in the UST area consist of the relatively light petroleum compounds typical of gasoline, including the aromatic volatile organic compounds (VOCs) benzene, toluene, and xylene (BTX) (LMS 1987; Weston 1988a; Weston 1989a). LMS' initial investigation of the UST area in 1987 determined that the gasoline release associated with the former UST was concentrated directly above bedrock at a depth of 12-16 ft below ground surface (BGS) (LMS 1987). Total petroleum hydrocarbons were measured at concentrations of up to 1650 ppm in the soils immediately adjacent to the former UST; benzene, toluene, and total xylenes in these soils were measured at 41.4, 380, and 354 ppm, respectively (LMS 1987). Concentrations of the BTX compounds in the UST area groundwater have been observed to range from below the detection limit ($\leq$5-25 ppb) to over 3000 ppb (Weston 1989c). Based on the information gathered during the course of several investigations, the BTX-contaminated groundwater plume was determined to extend to the southeast within an approximate 175-ft radius of the former UST (Weston 1989a).

IFG intends to take a proactive position towards the remediation of this issue. Detailed information on the UST groundwater issue is provided in the summary reports of previous investigations (LMS 1987; O'Brien & Gere 1987; Weston 1988a; Weston 1988b; Weston 1989a; Weston 1989b; Weston 1989c). LMS anticipates that IFG will maintain their direct

dialogue with Erik Kinsel of NJDEP regarding the management of this issue. A conceptual approach to IFG's remediation of the UST area is described in Chapter 6. LMS' recommendations for further action regarding this groundwater issue are provided in Chapter 7.

1.3.2 **Sludge Impoundment Area**

As discussed above, IFG's original (1986) NJPDES/DGW permit required that groundwater monitoring be conducted in the area surrounding four inactive sludge-drying impoundments (Figure 1-2). Industrial wastewater sludge from painting and plating processes was disposed of in these impoundments from 1962 through 1973. Subsequently, the dewatered slugdes were transported off-site for disposal. Information on the chemistry of this sludge is provided in Appendix B. The locations of these former impoundments (as well as the network of groundwater monitor wells which surround them) are shown on Figure 1-2.

IFG's NJPDES/DGW groundwater monitoring program was initiated to assess the potential release of constituents of the wastes contained in these inactive sludge impoundments to local groundwater. This program has involved the installation of a number of overburden and bedrock monitor wells to date (including the four monitor wells installed under LMS' supervision in October 1990). Monitor wells MW-1 (overburden) and MW-1A (bedrock) are considered upgradient wells and are located immediately north of the impoundments. Monitor well MW-16A was installed in October 1990 to further define upgradient conditions north of the impoundments in the proximity of Gold Run (see Section 2.1). Monitor well MW-17A was also installed at that time to better define upgradient conditions west of the impoundments. Overburden monitor wells MW-2, MW-3, MW-4, MW-5, and MW-6, are considered downgradient wells and are located clockwise around the perimeter of the impoundments from northeast to southwest, respectively (Figure 1-2). Bedrock monitor wells MW-13 (south) and MW-7A (southeast) are also downgradient of the impoundments (Figure 1-2). A summary of the 23 groundwater monitor wells included in IFG's quarterly sampling program (along with relevant technical information concerning the geology at their locations and their construction) is provided in Table 1-1. Similar information is provided for UST-5, which is proposed for inclusion in future NJPDES/DGW quarterly sampling events.

TABLE 1-1

SUMMARY OF WELL STATISTICS - 25 FEBRUARY 1991

Inland Fisher Guide, Trenton, NJ

WELL NAME	WATER ELEVATION	WATER-BEARING ZONE	TOTAL DEPTH (ft)	SCREENED OR OPEN INTERVAL (ft)	DESCRIPTION
MW-1	111.75	Overburden	10	4-9	Clay, silt, fill overburden; drilled to refusal.
MW-1A	110.49	Bedrock	40	33-40	Fill, silt, and sand overburden; bedrock at 23 ft
MW-2	102.55	Overburden	12	6-12	Clay, fill, and sand overburden; last 2 ft is weathered sandstone
MW-3	109.62	Overburden	12	4-11	Clay, fill, and sand overburden
MW-4	105.59	Overburden	12	5-12	Clay, sand, and fill overburden; 1 ft weathered sandstone
MW-5	104.58	Overburden	12	5-12	Mixed fill, clay over weathered sandstone
MW-6	104.50	Overburden	12	5-12	Mixed clay, sand, fill (CD?) over weathered sandstone
MW-7	109.19	Overburden	16.2	5.5-15.5	Silty sand over clay and fill; bitum fragments over weathered sandstone
MW-7A	105.45	Bedrock	40	35-40	Fill over weathered sandstone; water at competent rock surface (25 ft)
MW-8	119.29	Overburden	17	5.5-15.5	Clay and waste as fill over clay, sand, then weathered sandstone
MW-9	Dry	Overburden	15.5	8-15	Silt, CD fragments, fill, clay over competent bedrock
MW-9A	111.34	Bedrock	40	33-40	CD fill, sand, cobbles over shale and sandstone
MW-10	109.13	Overburden	15.9	5-15	Clay, fill, silty shale, sandy zone over sandstone
MW-11	107.43	Overburden	17.9	6.5-17.5	Clay, silt over weathered sandstone in bottom 3 ft
MW-12	108.53	Overburden	17.5	4-17.5	Silty sand over clay and 2 ft weathered sandstone at bottom
MW-13	103.29	Bedrock	40	21-40	Weathered shale and silt over sandstone
MW-14A	131.64	Bedrock	50	13-50	Blacktop over silt, sandstone, then siltstones
MW-15	106.13	Overburden	13	1.5-12	Silt over sand, weathered rock, then competent sandstone
MW-15A	107.45	Bedrock	28	18-28	Loam over varied overburden, then weathered rock and competent sand and siltstones
MW-16A	116.34	Bedrock	42	20-42	Mixed overburden over weathered rock, then wet sandstones and shales
MW-17A	132.65	Bedrock	35	10-35	Asphalt over weathered rock, then competent sandstones, shales
UST 5	-	Bedrock	20	10-20	Concrete over sand-to-clay mixed fill, then red sandstone
UST 7	110.59	Bedrock	115	100-115	Concrete over loose silt/clay and siltstone shale sequences to sandstone bottom
UST 8	114.07	Bedrock	50	21-50	Concrete over fill/debris over siltstone

As previously mentioned, the principal waste stream to the former impoundments originated from IFG's painting and plating processes (Appendix A). The volatile organic compounds (VOCs) used as solvents in IFG's painting and plating processes included trichlorobenzenes, dichlorobenzenes, toluene, methylene chloride, and trichloroethane (1,1,1-TCA) (Appendix A). IFG's historical records of solvent usage indicate that only minimal amounts of 1,1,1-TCA were purchased and used for degreasing equipment. These records demonstrate that the majority of TCA used on site was recycled--e.g. spent solvent was transported off-site to a solvent recycling facility. IFG's paint stripping operations also utlized minimal quantities of methylene chloride.

The limited VOC contamination observed in the monitor wells surrounding the impoundments consists of TCE and its degradation products, DCE and vinyl chloride, trichlorobenzene, dichlorobenzenes, chlorobenzene, benzene, 1,1,1-TCA and methylene chloride. 1,1,1-TCA is commonly associated with TCE and can be attributed to off-site sources.

In addition to the VOCs described above, these painting and plating processes generated wastes that contained several semivolatile compounds and metals, as demonstrated by the chemical data from samples of the sludge taken by representatives of the U.S. Environmental Protection Agency (EPA) and IFG (Appendix B). However, the overburden monitor wells immediately surrounding the impoundments have shown only sporadic "hits" (e.g., one to five detectable concentrations out of 13 total laboratory analyses) of certain semivolatiles. These semivolatiles include bis(2-ethylexyl) phalate (a common laboratory-related contaminant), d-in-butyl phalate, naphthalene, acenaphthene, fluorene, phenanthrene, and phenols (total recoverable).

The following metals have been detected in the shallow monitor wells surrounding the impoundments: arsenic, barium, cadmium, copper, lead, manganese, nickel, and zinc. However, some of these metals have also been detected in the upgradient monitor wells. Furthermore, groundwaters that occur in Triassic sedimentary rocks in the northeast, (including the Stockton Formation bedrock beneath IFG), are known to naturally exhibit

background concentrations of the following metals: barium, copper, iron, and manganese (see below).

1.3.3 Background (Upgradient) Conditions

1.3.3.1 *Natural Background.* Limited concentrations of certain metals in the groundwater at IFG, including iron, manganese, copper, and barium may be attributable to natural background conditions. Manganese is present at relatively significant concentrations in groundwaters that occur in the Stockton Formation. Although no data is available for iron concentrations in groundwater beneath IFG, iron is expected to be present at concentrations similar and/or higher than manganese. Degens (1965), Vinogradov (1959), and others have examined the natural distribution of these elements.

Iron occurs in crystalline rock of the Precambrian to 3.5% (as FeO) and 1.5% (as Fe_2O_3) (Blatt et al. 1972). It averages 0.7% (as FeO) and 1.5% (as Fe_2O_3) in feldspathic sandstones (Boggs 1987). It occurs to 1.74% (as FeO) and 4.0% (as Fe_20_3) in Mesozoic and Cenozoic shales (Boggs 1987). As the Stockton Formation is a Mesozoic feldspathic sandstone with interbedded shales, these values may serve as background concentrations for sedimentary iron concentrations at IFG. The sludge of this site was found to contain 3800 mg/kg, or 0.38% (Appendix B).

Manganese is reported to average 0.2% as MnO in feldspathic sandstones and in trace amounts in shales of Mesozoic and Cenozoic age (Boggs 1987). Vinogradov (1959) offers a range of manganese concentrations in soil as 0.01 to 0.4%. Manganese was measured at 43 mg/kg (ppm) (equivalent to 0.0043%), in a sample of sludge obtained from IFG. Goldschmidt (1954) reports the proportion of manganese and iron in certain rocks (found to be in chemical equilibrium), to be 0.0131. This ratio is close to that measured in the sludge at IFG.

Copper is a common element in Triassic sedimentary rocks of the eastern United States, such as the Stockton Formation bedrock present beneath IFG. Copper has been reported to reach 150 ppm in the Ladentown Basalt of the Newark Basin by Puffer (1984) and Puffer and Lechler (1980). Vinogradov (1959) gives an average copper content in soils of 20 ppm.

Copper was measured at 55 ppm in a background soil sample taken from a location north of the sludge impoundments at IFG (Appendix B).

Degens (1965) discusses the various sedimentary environments in which copper and copper minerals are stable. Fresh water shales (such as those in the Stockton Formation) are reported to contain over 1000 ppm copper (Degens 1965). Similar characteristics are noted for other Triassic sedimentary rocks, such as those in Connecticut (Gray 1982; deBoer 1968).

Copper was detected in one groundwater sample from upgradient bedrock well MW-14 (25 ppm). Two wells showed elevated concentrations of this metal: MW-11 (≈85 ppb Cu average of 13 analyses) and MW-8 (70 ppb Cu in one sample only). The overburden monitor wells downgradient of the impoundments average only trace (≤10 ppb) concentrations of copper. Low background concentrations of dissolved copper in the site's groundwater are most likely attributable to the solution of copper minerals present in the overburden clays and bedrock shales beneath IFG. The fine grained strata observed in the overburden beneath IFG, (as well as the shales present in the Stockton bedrock), are known to be metal traps; therefore, the site's geology may attuenate the subsurface migration of copper and other dissolved metals.

Barium has also been measured in the groundwaters beneath IFG. Barite ($BaSO_4$) is a common barium mineral in Triassic sediments. Barite is also associated with volcanic rocks found north of the Trenton area. Brobst (1965) has shown barite to be the most common Ba-mineral in the Triassic basins of the northeast; deBoer (1968) and Fritts (1962) have mapped several barite mines in the Triassic. Vinogradov (1959) reports an average value of barium in soils to be 500 ppm.

Barium was measured at 330 ppm in a background soil sample taken at IFG (Appendix B). Barium has been commonly detected in most of the groundwater monitor wells on site at average concentrations of ≥550 ppb in bedrock and ≥1200 ppb in overburden (Chapter 4). Barium has been detected in all of the upgradient bedrock wells, e.g., MW-1A (598 ppb average), MW-14 (200 ppb average), MW-16A (300 ppb), and MW-17A (380 ppb).

Although barium compounds have been used in small quantities in IFG's plating processes, (Appendix A), the prevalence of barium in IFG's upgradient groundwater monitor wells suggests that it is related to background conditions. The potential contribution of upgradient sources of barium to local groundwater is not known.

1.3.3.2 *Upgradient Sources of Groundwater Contamination.* The Naval Air Propulsion Center (NAPC) is located directly across Parkway Avenue from IFG. Since the principal directions of both surface water drainage and groundwater flow in the area have been determined to be to the south and east, NAPC is considered upgradient of IFG for the following reasons: (1) it is topographically higher than IFG and (2) it is both west and north of IFG.

IFG personnel met with representatives of NAPC on 31 March 1991. NAPC and IFG agreed to share information concerning their respective groundwater investigations at this meeting. NAPC officials informed IFG that several overburden monitor wells have been installed at their facility. Records reviewed since the meeting indicate that groundwater samples obtained from these overburden wells have shown significant concentrations of trichloroethylene (TCE), a common industrial solvent. Concentrations of TCE in the groundwater beneath the NAPC are reported to range from 50-500 ppb.

Subsequent to the 31 March 1991 meeting, IFG obtained a copy of the Initial Assessment Study (IAS) report pursuant to their filing a request under the provisions of the Freedom of Information Act with the NJDEP. This report provided information on the environmental conditions at NAPC based on a limited investigation conducted by BCM. NAPC officials have informed IFG that a final site investigation (FSI) of their facility has recently been completed. IFG has just received a copy of the final report on the FSI (prepared by IT Corporation); however, LMS has not reviewed the FSI in detail as part of this project. IT Corporation is currently developing the work plan for a Phase III remedial investigation/feasibility study (RI/FS).

LMS review of the IAS report has revealed the following information:

- NAPC has used significant quantities of TCE as a heat-exchange medium in cooling towers since 1955. These cooling towers are located in the Brine

Handling Area (Site No. 1 as designated by NAPC officials). The cooling towers have an operational volume of 25,000 gal. Over 50,000 gal of TCE have been replaced in the system since 1955; however, the NAPC's consultants have estimated that only 500 gal have leaked from this system to the ground surface.

- Three reported spills of TCE have occurred at NAPC. The total estimated volume of TCE lost as a result of these spills is estimated at 1200 gal.

- All of the surface water drainage from the industrialized portions of the NAPC site ultimately discharges to Gold Run. A surface water sample from a drainage ditch located near the Brine Handling Area showed concentrations of TCE, 1,2-trans-dichloroethylene (DCE), and vinyl chloride approaching 1 ppm. This drainage ditch discharges to Gold Run through a system of culverts.

The environmental conditions at the NAPC facility (as described in the IAS report) are evaluated in greater detail in Chapter 5. A historical record search has failed to find any instances of the use of TCE at the IFG facility, leading to the deduction that the TCE found in groundwater on the IFG site is attributed to the NAPC, upgradient source.

CHAPTER 2

SUMMARY OF FIELD ACTIVITIES

Two principal technical objectives of this project are different from those of previous investigations conducted at IFG: (1) the evaluation of upgradient influences on groundwater quality and (2) the investigation of Gold Run's influence on local groundwater flow and contaminant migration. Consequently, the field activities of this project were designed to provide additional information on these issues.

2.1 MONITOR WELL INSTALLATION

As mentioned in Chapter 1, the locations of the four additional monitor wells were discussed and finalized at the 3 October meeting with NJDEP. A summary table of these wells, including their location and the rationale for their installation, is provided below:

NEW MONITOR WELL	LOCATION	RATIONALE FOR INSTALLATION
MW-16A (Bedrock)	Northeast corner of site near west bank of Gold Run as it enters site from beneath Parkway Avenue	Evaluation of upgradient facility (NAPL) on groundwater quality at IFG as well as groundwater conditions adjacent to west bank of Gold Run
MW-15 (Overburden)	Near east bank of Gold Run between Parkway Avenue and MW-3	Evaluation of groundwater conditions adjacent to east bank of Gold Run
MW-15A (Bedrock)	Adjacent to MW-15	Evaluation of groundwater conditions adjacent to Gold Run and vertical distribution of contaminants in groundwater west of Gold Run
MW-17A (Bedrock)	Adjacent to west face of main Bldg. ?700 ft south of MW-14A	Evaluation of upgradient groundwater conditions west of IFG

The three additional wells near Gold Run were installed to evaluate the interaction of this stream with the shallow groundwater system; this component of the investigation is discussed in great detail in Section 3.3.

Eric Hince (LMS' geologist on site) provided the oversight for the installation of the above-cited monitor wells from 4 to 6 October 1990. The monitor well installation was performed by LMS' subcontractor, Summit Drilling Company, with a Mobil B-80 drill rig. Installation of each of the new bedrock monitor wells was performed with the downhole air-hammer technique according to the following procedure:

- An 8-in. diameter borehole was advanced with an air-hammer from the ground surface to approximately 10 ft into competent bedrock. Cuttings were removed by continuously purging the borehole with air.
- A 6-in. inside diameter (ID) carbon steel casing was set from ≈10 ft into competent bedrock to above the ground surface.
- The annulus between the 8-in. borehole and casing was grouted with a 10:1 cement/bentonite grout. The grout was permitted to set for a minimum of 12 hrs.
- A 6-in. diameter borehole was advanced from between 10 and 25 ft below the base of the casing.
- The final cuttings from the base of the 6-in. open-rock borehole were purged by surging the borehole with compressed air.
- The bedrock wells were developed with air forced through the drilling tools set at the base of the well. All of the bedrock wells were developed for over 1 hr.
- A locking cap was installed and a mound of cement was installed around the contact between the ground surface and casing.

The new overburden well (MW-15) was installed with the air rotary method according to the following procedure:

- A 6-in. borehole was advanced with a tri-cone roller bit from the ground surface to the top of competent bedrock at ≈13 ft BGS. Cuttings were removed by continuously purging the borehole with air.
- 1 ft of Morie No. 0 sand was placed at the base of the borehole; subsequently, a 10-ft section of 4-in. ID, continuous slot 304 stainless steel well screen was set in the borehole from 12 to 2 ft BGS.
- A 4-in. ID flush-threaded 304 stainless steel riser was installed from the top of the well screen at 2 ft BGS to above the ground surface.

- A filter pack of Morie No. 0 sand was installed in the annulus between the borehole and well screen/riser to approximately 0.75 ft above the top of the well screen. Subsequently, a ≈9-in. seal of bentonite pellets was emplaced above the sand pack to ≈0.5 ft BGS and a 6-in. cap of cement was emplaced from 0.5 ft to the ground surface.

- A protective (outer) steel casing with a locking cap was set in concrete grout from ≈0.5 ft BGS to above the ground surface. Subsequently, a mound of cement was installed around the contact between the ground surface and protective casing.

- MW-15 was developed with air forced through the drilling tools set at the base of the well for ≈20 min (the purge water was observed to be turbidity-free at that time).

The boring logs for the above-mentioned monitor wells, as well as their As-Built certifications (NJDEP Form A's) and Surveyor's Certifications (NJDEP Form B's) are included in Appendix C.

2.1.1 Health and Safety Air Monitoring

Air monitoring of the workspace breathing zone was performed throughout the monitor well installation activities by Eric Hince of LMS with an Hnμ photoionization detector. In addition, periodic measurements were obtained from both the borehole and drill cuttings (via headspace analysis) with the Hnμ. Elevated (≤700 ppm) concentrations of vapor-phase volatile organic compounds (VOCs) were measured in the boreholes advanced for monitor wells MW-16A and MW-17A. Headspace analysis of cuttings obtained from MW-16A and MW-17A revealed total concentrations of vapor-phase VOCs of up to 20 ppm and 230 ppm, respectively.

Concentrations of VOCs were measured above the health and safety action level of 5 ppm in the breathing zone only during the advancement of the borehole for MW-17A (beneath a depth of approximately 10 ft BGS). Consequently, LMS and Summit Drilling personnel wore Level C personal protective equipment for the completion of MW-17A.

A summary table of LMS' air monitoring measurements recorded during the drilling activities is included in Table 2-1. LMS' field notes for the health and safety air monitoring program are included in Appendix D.

2.2 GROUNDWATER SAMPLING

LMS sampled 23 new and existing groundwater monitor wells at IFG-Trenton during the period of 29 October through 2 November 1990 (Table 1-1). The equipment and procedures used by LMS' field crew are the same as those of previous sampling events (referenced in IFG's current NJPDES/DGW permit) with one exception: LMS utilized in-line filters for the metals samples as opposed to the previously used filter and funnel apparatus. This change in procedure was discussed and verbally approved at the 3 October 1990 meeting; formal approval was granted in subsequent communication between IFG and Erik Kinsel of NJDEP-Division of Water Resources.

LMS personnel performed a portion of the October-November 1990 groundwater sampling under the supervision of Mr. Matthew J. Maffei from NJDEP-Central Bureau of Enforcement. Duplicate samples were obtained by NJDEP from some of the wells sampled by LMS. Groundwater samples obtained by LMS were documented and packed in coolers at the end of each work day. LMS transferred custody of the samples to personnel from Northeast Analytical Corporation (NAC) on a daily basis. These samples were analyzed by NAC at their Marlton, New Jersey, laboratory (NJDEP certification No. 03117).

2.3 SURFACE WATER-GROUNDWATER INTERACTION STUDY

The original scope of work for the investigation of the interaction of Gold Run with the shallow groundwater system was developed by Weston (Weston, 1989c). This approach involved the installation of a staff gauge in Gold Run near MW-13 and the subsequent measurement of water levels at this staff gauge and from monitor wells MW-13, MW-5, and MW-6 twice per day for a period of one week. This approach was proposed as *Task 3: Groundwater and Surface Water Head Measurements* in the *Groundwater Remediation Plan* previously submitted to NJDEP (Weston, 1989c).

Measurements Obtained with an Hnu Photolonization Detector In ppm

MW Boring/Date	Depth BGS	Breathing Zone	Borehole	Cuttings	Note
MW-16A	Calibration				High Calibration
10/4	Background	0-.5			
	0-5 ft	0-.5			Background
	5-10 ft	0-.5			Background
	10-15 ft	0-.5			Background
	15-20 ft	0-.5			Background
	20 ft		5.5		
10/5	10 ft		25		Redrill Grout
	10-20 ft	0.6			Background
	20 ft		0-0.6		Background
	37 ft		400		Change Rods
	37 ft	1-2			Slight Deflection
	37 ft	0.6-0.8			
	40 ft			10	Cuttings (Headspace)
END OF BORING	42 ft			20	Cuttings (Headspace)
	42 ft			15-20	Cuttings (Headspace)
	42 ft	2-5			Brief Deflection (Windy)
	42 ft	0.6-1			- Deflection (Humid)
	42 ft		5		Drill Stem
	42 ft		3.8		Rods Removed
	42 ft		700		MW Casing with Cap On
	42 ft	1-2			MW Cap Open
MW-15A	Calibration				High Calibration
10/4	Background	0-.6			
	0-5 ft	0-.6			Background
	5-9 ft	0-.6			Background
	9 ft		4		
	11 ft	0-.6			Background
	15 ft	0-.6			Background
	15 ft		0.5-1.4		
	18 ft	0-.6			Background
	18 ft		0.5-1		
10/5	Calibration				High Calibration
	18 ft		1.2		
	18-20 ft	0-.6			Background
	20-25 ft	0-.6			Background
END OF BORING	28 ft	0-.6			Background
	28 ft		1		
MW-15	Calibration				High Calibration
10/5	Background	0-.6			
END OF BORING	0-13 ft	0-.6			Background
	0-13 ft		5-7		Saturated Overburden
MW-17A	Calibration				High Calibration
10/6	Background	2			Fogged Lamp?
	0-3 ft		20		
	3 ft	1-1.5			
	9-10 ft	3-4			Adjacent to Borehole
	10 ft	1-2			
	10 ft		<100		Wild Needle (Humid)
	10 ft	3-10			Proceed in Level C
	10 ft	2-3			
	10 ft		500-700		2 ft into Borehole
	11-12 ft	3-7			Level C
	12-13 ft	2-7			Level C
	13-16 ft	1-7			Level C
	16 ft		20-25		
	17-20 ft		30-60		
	17-20 ft	0.2-2			
	20-35 ft	0.2-1.5			
	26 ft		10		
END OF BORING	35 ft		350-700		Before Development
	35 ft		0.2-0.6		After Development
	35 ft			230	Cuttings (Headspace)

Prior to the 3 October 1990 meeting, LMS and IFG discussed the technical components of this task at length. Subsequently, it was decided that the program recommended by Weston was insufficient to meet the desired technical objectives. Therefore, LMS and IFG developed a plan to obtain continuous head measurements from three pairs of monitor wells and stilling wells in adjacent reaches of Gold Run. The continuous water level measurements were to be obtained with the installation of Stevens recorders at these locations. IFG proposed this alternative scope at the 3 October 1990 meeting and received a positive response from Erik Kinsel of NJDEP. Subsequent communications between IFG and NJDEP resulted in the formal approval of this revised approach.

The technical objectives of this task were:

- To obtain a time series of continuous head measurements from each of the paired installations (as opposed to isolated measurements).
- To observe the response of both the groundwater and surface water systems to storm-induced recharge events.
- To observe the interaction of the groundwater and surface water systems over a natural cycle of fair weather→storm→fair weather conditions.

2.3.1 Installation of Stevens Recorders

On 28 and 29 November 1990 LMS installed three pairs of Stevens Recorders in monitor wells and stilling wells in adjacent reaches of Gold Run. The stilling wells installed in Gold Run were constructed of 6-ft sections of 6-in. inside diameter (ID) carbon steel casing. IFG personnel custom-fitted each stilling well with one to three 6-in. vertical stabilizers by welding 0.5-in. diameter sections of rebar to the base of the casings. Each stilling well was driven into the stream bed to refusal with a sledge hammer and secured in place with rope harnesses fastened to trees along the stream bank.

LMS installed the first paper chart in each of the Stevens Recorders to start the first eight-day recording cycle. The recorders were allowed to run for a period of approximately one month (through 27 December 1990), during which time IFG personnel changed the chart paper in each recorder every six to eight days. The locations and elevations of the stilling

wells were surveyed by Lippincott Engineering Associates to the same horizontal and vertical tolerances as the monitor wells on site (±0.001 in. latitude/longitude and ±0.01 ft vertical).

An overview of the deployment of the Stevens Recorders, in terms of both their location and the objectives of their installation, is provided below:

MONITOR WELL	STILLING WELL	LOCATION OF STEVENS RECORDER STATION	OBJECTIVE OF INSTALLATION
MW-16A	SW-16A	Adjacent to and within west bank of northernmost reach of Gold Run on IFG's property, respectively	Investigation of the interaction of Gold Run and the uppermost portion of the bedrock water-bearing zone at this location
MW-15	SW-15	Adjacent to and within east bank of middle reach of Gold Run on IFG's property, respectively	Investigation of the interaction of Gold Run and the overburden/ fractured rock water-bearing zone at this location
MW-13	SW-13	Adjacent to and within east bank of southernmost reach of Gold Run on IFG's property, respectively	Investigation of the interaction of Gold Run and the uppermost portion of the bedrock water-bearing zone at this location

The original recorder installed in SW-13 did not function properly, and a replacement was shipped to IFG and installed on 11 December. A malfunction occurred in the recorder installed in MW-15, which resulted in the failure to record data beyond 22 December. A similar malfunction in the replacement recorder installed in SW-13 resulted in the loss of data beyond 22 December. However, the other Stevens Recorders operated flawlessly and provided excellent data. In addition, more than one to two weeks of quality data were collected from SW-13 and MW-15 as well. The data plots are shown in Appendix F.

CHAPTER 3

SITE GEOLOGY, HYDROGEOLOGY, AND SURFACE WATER HYDROLOGY

As previously mentioned, the IFG facility is located in Ewing Township, north of Trenton, New Jersey. The site is located in a fluvial drainage basin to the north and east of the Delaware River. The watershed general topographic dip and stream flow are all south to southwest. This region exhibits generally subdued relief and low topography (e.g., 50 to 350 ft of elevation). Land use ranges from moderate to intense development, especially near the major highways and rail rights-of-way. Two streams, the Shabakunk and Gold Run Creeks, provide surface drainage for the area in the vicinity of IFG. Both streams flow towards the south and west and terminate in the Delaware River. Gold Run enters IFG's property from the north by way of a culvert beneath Parkway Avenue. Gold Run flows south-southwest through IFG's property and separates the developed portion of the site to the west from that which is undeveloped to the east (Figure 1-2).

Mercer County includes parts of two geomorphic provinces: the Piedmont lowlands and the Atlantic coastal plain. The contact between these two provinces is identified by a ridge of Paleozoic and Precambrian metamorphic rocks that outcrop well south of the site and along the banks of the Delaware River. The ridge is exposed at the falls (i.e., the fall line) at Trenton.

3.1 GEOLOGY

3.1.1 Surficial Soils

Surface and near-surface soils at this site are reported to be mixed "cut and fill" of undefined identity and composition. In addition to fill material obtained from local sources, these soils are likely to include local soils that have been reworked by construction activities. The original soils on site and/or the local sources of fill probably consisted of deeply weathered, well-drained upland soils. IFG's boring logs show that the native soils, where undisturbed, comprise the uppermost 1-2 ft of unconsolidated sediment on site. In general, the soil

horizon is least disturbed in the northern and eastern portions of the site in the vicinity of Gold Run. By comparison, the heavily reworked areas within the southern and central portions of IFG's complex contain as much as 4-10 ft of mixed fill, soil, and overburden sediments.

The Mercer County New Jersey Soil Conservation Service identifies the local soil types as *Sassafras* and *Matapeake* soils (Tedrow [1986] uses the name *Galestown* for *Matapeake*). Regardless of their nomenclature, these soils were developed from preexisting fluvial and glacial outwash sediments. The uppermost sandy facies of these sediments were reworked and developed into the *Sassafras* soils. The finer-grained sediments associated with the generally broad, flat, and periodically flooded areas developed the *Matapeake* (or *Galestown*) soil cover.

Both the *Sassafras* and *Matapeake* soils are generally well-drained. The shallow horizons of the *Sassafras* display permeabilities of up to 2 in./hr (≈1500 ft/yr). The deeper *Matapeake* soils display significantly lower permeabilities of ≤0.2 in./hr (≈150 ft/yr). Barriers to infiltration into the underlying overburden and/or bedrock are unknown and/or undescribed for these soils. Given the well-drained and generally permeable nature of these soils, they are likely to provide significant recharge to the overburden groundwater beneath them.

3.1.2 Overburden Geology

Overburden geology in the vicinity of IFG is reported to include a complex mix of preglacial riverine and floodplain deposits. These unconsolidated sediments include interbedded fluvial sandy silts and clays, sands, and gravels, which unconformably overlie bedrock of Triassic age. A thin (1-4 ft thick) zone of loose, heavily weathered and highly permeable sandstone is present between the base of the overburden sediments and the top of competent bedrock in most areas.

The fluvial overburden sediments observed beneath IFG have been investigated and mapped by Bowman and Lodding (1969), Minard and Rhodehamel (1969), and Owens and Minard (1962, 1975). Outwash sands and gravels are found to the south and west of IFG, and are associated with deglaciation. They were deposited by meltwater streams flowing usually

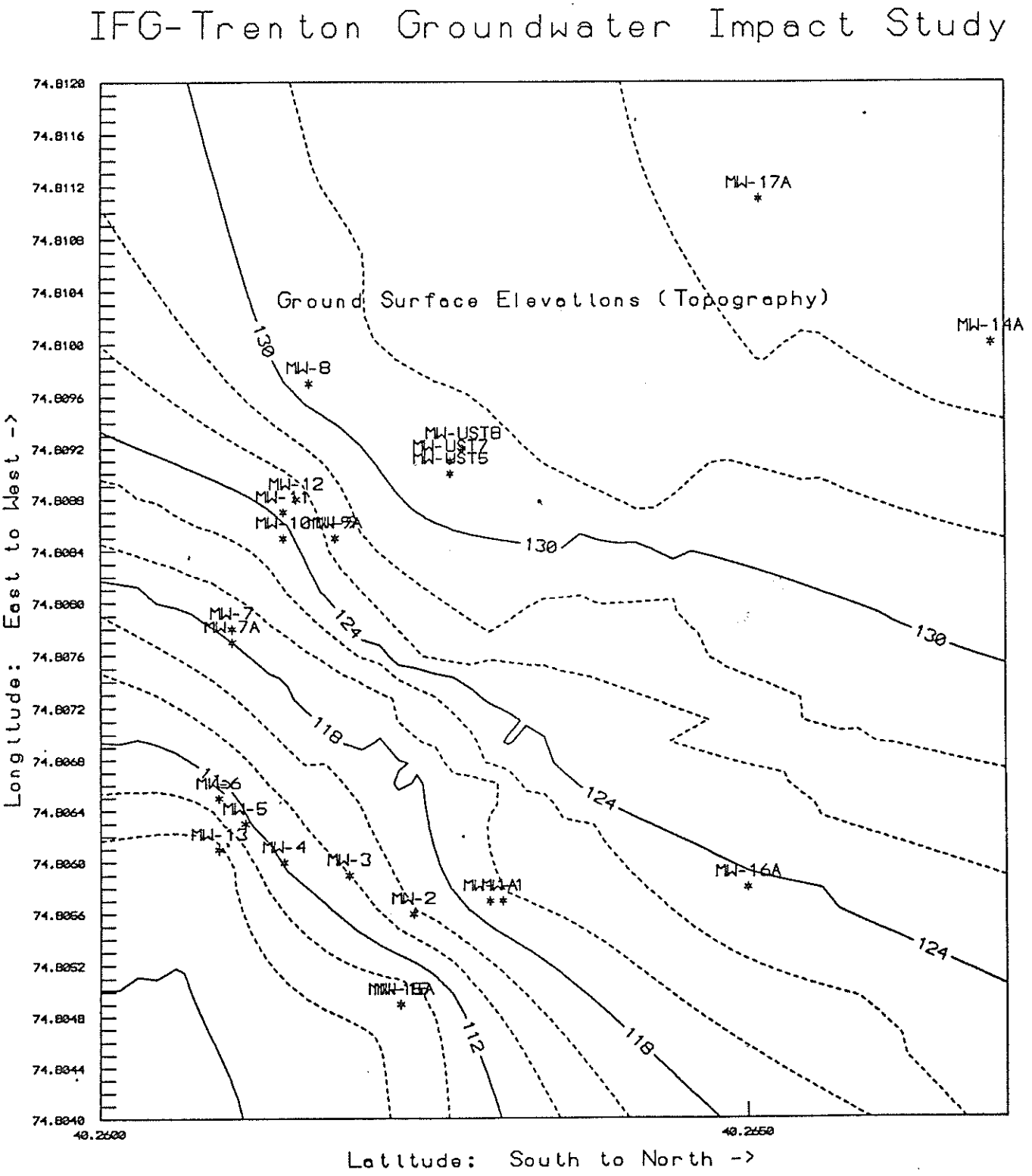
generally southward from the receding glaciers (Owens and Minard 1975). The fluvial sediments are those associated with interglacial or preglacial time, when streams other than those produced by glacial meltwater were depositing sediment in a subaerial environment.

LMS' review of the available boring logs from IFG confirms the fluvial description of these sediments provided in previous work (Bowman and Lodding 1969; Minard and Rhodehamel 1969; Owens and Minard 1962, 1975). The fluvial origin of the overburden material observed at IFG is supported by the lithology and stratigraphy. The observed (and inferred) presence of erosional stream channels within and along the bedrock surface also supports a fluvial origin. LMS' review of IFG's boring logs suggests the presence of a north-south trending buried stream channel (or erosional surface on top of competent bedrock or fracture) in the center of the site beneath the approximate location of the UST area. Buried stream channels are also reported to exist to the south and west of IFG (Owens and Minard 1975). The potential effect of such features on the hydrogeologic character of the site is to emphasize groundwater flow volumes through these channels.

The overburden sediments observed at IFG strongly reflect the composition of the bedrock beneath them. The Stockton Formation beneath the site is comprised of arkosic, hematite-stained sedimentary rocks of Triassic age. As the layer of fluvial overburden material overlying the Stockton is relatively thin, the initial hypothesis, based upon a knowledge of soil development, would be that it is likely to reflect a mineral composition similar to that of the Stockton. The lithology of the overburden sediments noted in IFG's boring logs confirms this hypothesis. The unconsolidated deposits observed at IFG have been termed Tar2, (e.g., Tertiary [age] Arkose [composition] No. 2) by Owens & Minard (1975).

The site-specific topographic relief of the overburden surface at IFG is shown in Figure 3-1, which was developed by inputting the surveyed coordinates and elevations of the ground surface at each monitor well location into a commercial software package (Surfer). Interpolation between data points was performed in Surfer by Kriging (Watson 1984; Journel and Huijbregts 1978). A detailed description of the software settings, assumptions, and anticipated errors of such representations is provided in Chapter 4.

FIGURE 3-1


IFG-Trenton Groundwater Impact Study
Ground Surface Elevations (Topography)
Longitude: East to West ->
Latitude: South to North ->
74.8120
74.8116
74.8112
74.8108
74.8104
74.8100
74.8096
74.8092
74.8088
74.8084
74.8080
74.8076
74.8072
74.8068
74.8064
74.8060
74.8056
74.8052
74.8048
74.8044
74.8040
40.2600
40.2650
130
124
118
112
MW-17A
MW-14A
MW-8
MW-UST8
MW-UST7
MW-UST5
MW-12
MW-11
MW-10
MW-9A
MW-7
MW-7A
MW-6
MW-5
MW-13
MW-4
MW-3
MW-2
MW-1A1
MW-16A
MW-18A

3.1.3 Bedrock Geology

The uppermost bedrock unit beneath the overburden of the IFG site and its immediate surroundings has been identified through previous investigations as the Stockton Formation (LMS 1987; O'Brien & Gere 1987; Weston 1988a; Weston 1988b; Weston 1989a; Weston 1989b; Weston 1989c). The Stockton Formation is part of the larger Newark Group of Triassic-aged sedimentary rocks which originated within the depositional system of an ancestral stream system draining an upland to the southeast (Widmer, 1964). The Stockton Formation consists of "cycled" strata of fine-to-medium grained sandstones, coarser-grained sandstones and conglomerates, and finer-grained siltstones and mudstones (shales). However, strata of conglomerates and cemented coarse-grained sandstones are not as common as the other lithologies within the Stockton Formation. The strata of the Stockton Formation (as well as other formations in the Newark Group) are typified by their nearly homogenous rust to deep red-brown coloration caused in part to hematite (iron) staining. However, some Stockton-age subunits exhibit the blue-green coloration indicative of copper staining. While the iron-rich staining is dominant in the Stockton observed at IFG, the boring advanced for MW-17A (as well as for several previous borings) encountered 1-2 ft of copper-stained strata. Therefore, it is not unlikely that background concentrations of iron and copper may be present in the site's soils and groundwater (Degens 1965).

The Stockton Formation occurs as outcrops and bedrock as far north of IFG as Rockland County, New York, and south to its contact with the ridge of Paleozoic and Precambrian metamorphic rocks found along the Delaware River. LMS' review of boring logs for monitor wells completed into the bedrock at IFG has shown that fine-to-medium grained sandstones and shales dominate the strata of the Stockton Formation observed on site. IFG's boring logs show that approximately 1-4 ft of relatively soft, heavily weathered and fractured sandstone overlies the "competent" bedrock surface, as indicated by the refusal of split spoons. The transition from fractured to competent bedrock in the subsurface is typically marked by a compositional change from the sandstone to harder, finer-grained siltstone and mudstone strata.

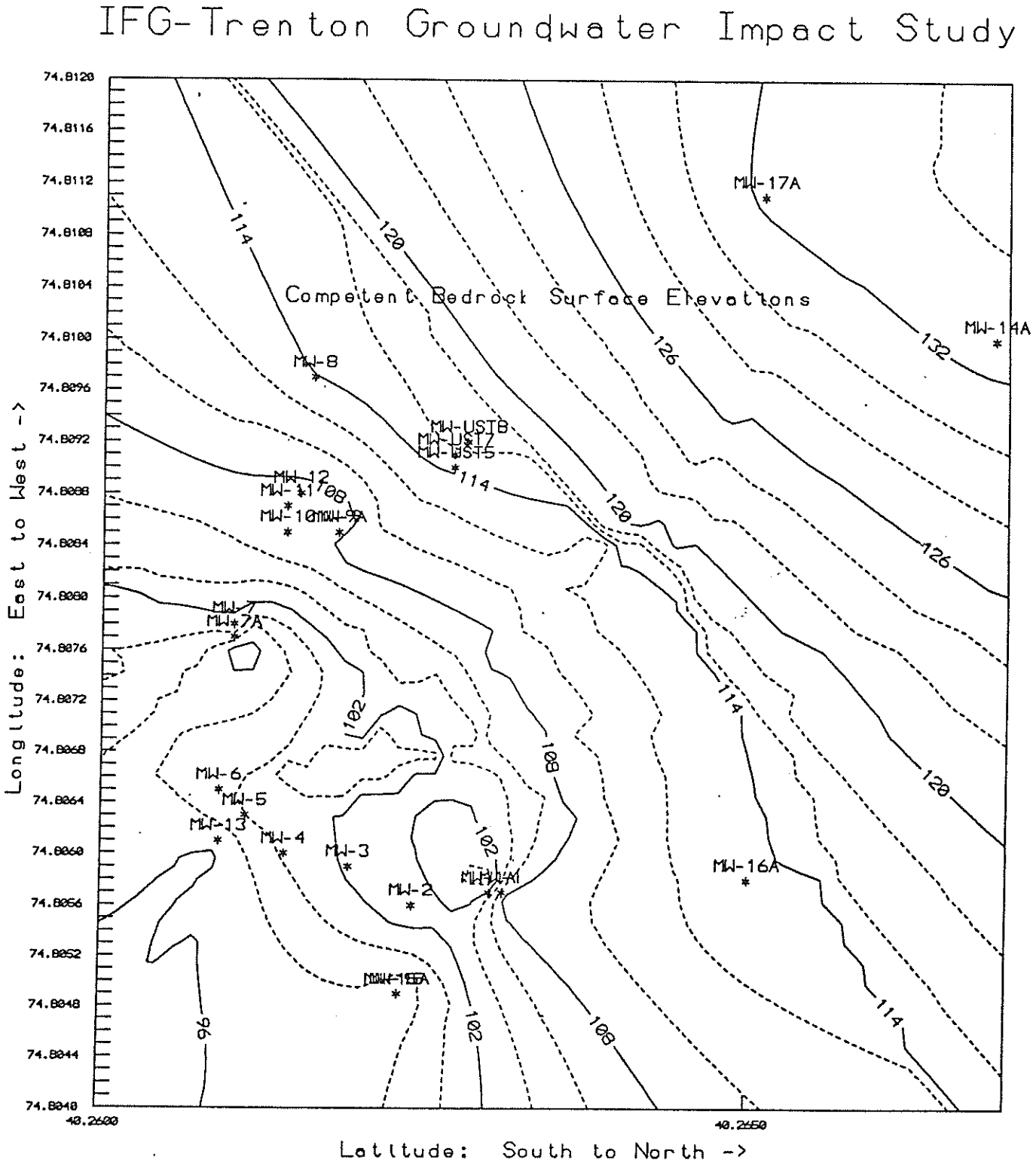
The geometry of the competent bedrock surface beneath IFG is depicted in Figure 3-2. The methods employed in the construction of Figure 3-2 are similar to those for Figure 3-1 noted above. As illustrated by Figure 3-2, the competent bedrock surface slopes from the northwest (≥132 ft of elevation near MW-14 and MW-17A) to the southeast (≤98 ft of elevation near MW-13, MW-15, and MW-15A). Figure 3-2 depicts an unknown feature on the bedrock surface beneath the central portion of the site. This feature on Figure 3-2, coupled with the bifurcation noted on the spatial distribution maps of selected groundwater contaminants (see Chapter 4) suggests the presence of a structural irregularity which has a controlling effect on overburden groundwater flow parts. Irregularities in the bedrock surface geometry beneath the site can be attributed to both the large-scale structural deformation of the Stockton Formation and the localized effects of fluvial sculpturing on the varying lithologic character (particularly hardness) of the uppermost strata of the Stockton Formation.

The Stockton Formation plunges at low angles under the Lockatong Argillite Formation to the north and west. The Stockton and the Lockatong formations are both deformed and dip in that direction, although the angles of dip vary depending on degree of structural deformation. The bedding planes in the Stockton beneath IFG dip to the northwest at ≈8 to 10° (Widmer 1965). It is noteworthy that the dip of the bedding planes is in the opposite direction of the slope of the competent bedrock surface, which is towards the southeast. This situation could greatly complicate the migration and fate of dense nonaqueous-phase liquid (DNAPL) contaminants such as TCE and its degradation products from the NAPC (see below).

3.2 HYDROGEOLOGY

Two groundwater-bearing zones have been identified beneath IFG. The uppermost saturated zone occurs in the overburden and the second occurs in the underlying Stockton Formation. The overburden groundwater is unconfined; however, some of the monitor wells (e.g., MW-1, MW-8, and MW-9) are either intermittently or typically dry. Therefore, groundwater occurrence at water table conditions in the overburden is nonuniform. The groundwater in the Stockton Formation is found to be under semiconfined conditions as indicated from water level measurements taken from well couplets (MW-1 and MW-1A, MW-7 and MW-7A,

FIGURE 3-2


IFG-Trenton Groundwater Impact Study
Competent Bedrock Surface Elevations
Longitude: East to West ->
Latitude: South to North ->
74.8120
74.8116
74.8112
74.8108
74.8104
74.8100
74.8096
74.8092
74.8088
74.8084
74.8080
74.8076
74.8072
74.8068
74.8064
74.8060
74.8056
74.8052
74.8048
74.8044
74.8040
40.2600
40.2650
MW-17A
MW-14A
MW-8
MW-USTB
MW-UST7
MW-UST5
MW-12
MW-11
MW-10
MW-9A
MW-7A
MW-6
MW-5
MW-13
MW-4
MW-3
MW-2
MW-1A
MW-16A
MW-15A
96
102
108
114
120
126
132

MW-9 and MW-9A, and MW-15 and MW-15A). Previous hydrogeologic investigations of the IFG site have been conducted since 1986 (LMS 1986; LMS 1987; O'Brien & Gere 1987; Weston 1988a; Weston 1988b; Weston 1989a; Weston 1989b; Weston 1989c). Information on the construction of the existing monitor wells on site is provided in Table 1-1; their locations are shown on Figure 1-2.

3.2.1 Overburden Hydrogeology

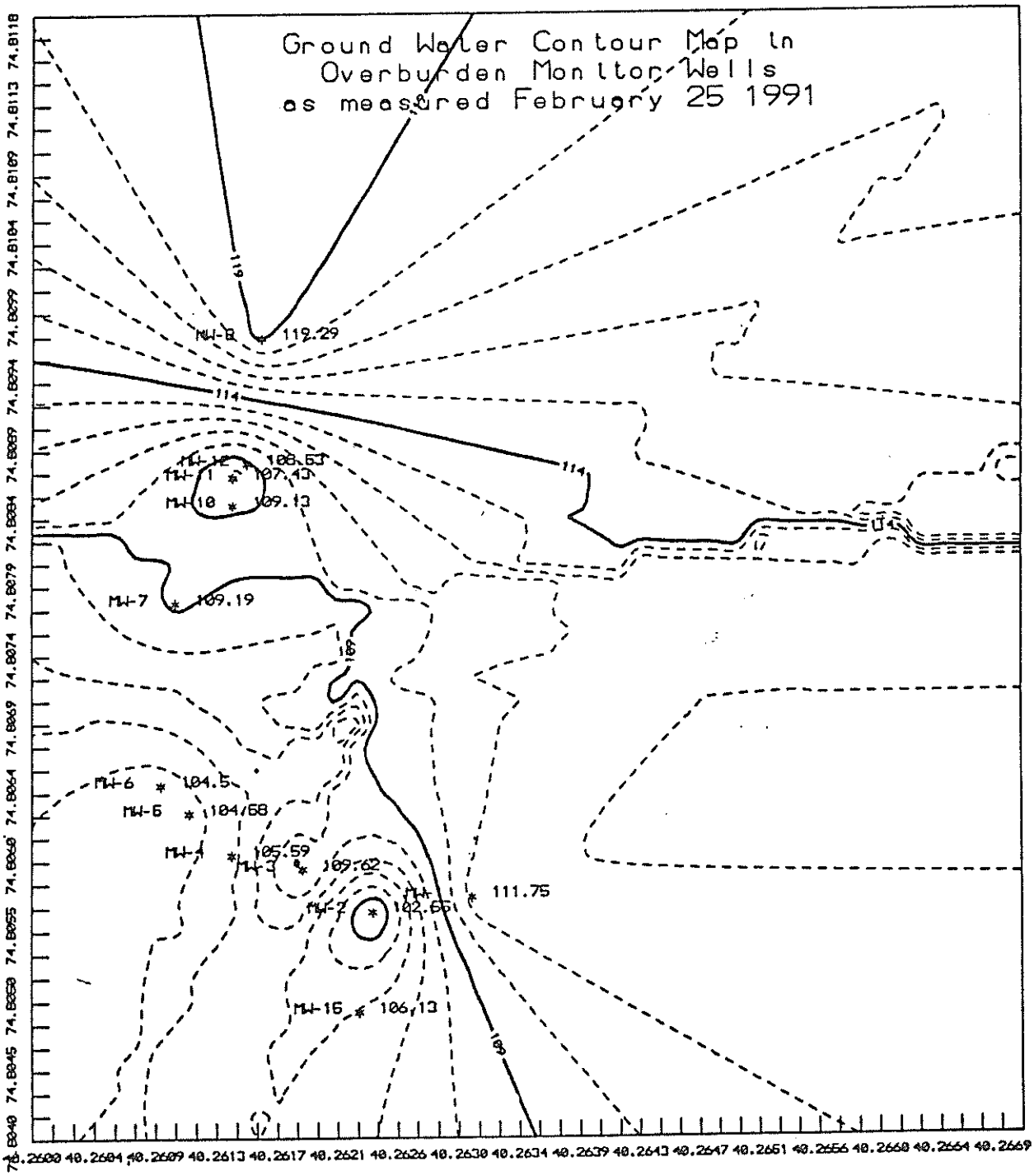
Overburden sources of groundwater have generally not been developed for commercial, industrial, or domestic use anywhere in Mercer County (Widmer 1965). As mentioned above, unconfined groundwater is found to be absent or sporadically absent in some overburden wells which are installed just above bedrock. Previous investigations have suggested that groundwater occurs in overburden sediments where thickness exceeds 10 ft (Weston 1989c). Previous work has suggested that the net flow direction of overburden groundwater is to the southeast under a horizontal gradient of ≈0.02 ft/ft (Weston 1989a). However, Weston (1989b) noted a southward component of flow in the vicinity of the UST area. Based on LMS' investigation of Gold Run (Section 3.3) and the observations noted above, the ≈0.02 ft/ft horizontal gradient calculated by Weston (1989a) may be valid only for its period of observation. LMS' work suggests that pronounced groundwater flow in the overburden is "episodic" in response to meteorological forcing (Section 3.3). Furthermore, flow conditions in the overburden vary beneath different portions of the site (see below).

Figure 3-3 illustrates the geometry of the water table surface based on water level measurements from overburden monitoring wells on 25 February 1991. This contour map was generated using the Surfer package. The absence of overburden monitoring wells in the northern half of the site has given rise to generally inferred contour lines for this portion of the map. In spite of this fact, a clear flow direction from west to east can be discerned across the southern half of the site from this map.

Figure 3-4 is a plot of the same data which has been "regridded" by the software package to an area restricted to that for which there is a comprehensive spread of data points, i.e., the southern half of the site. The contour map is more reliable as a result, because less inference

FIGURE 3-3

IFG-Trenton Groundwater Impact Study

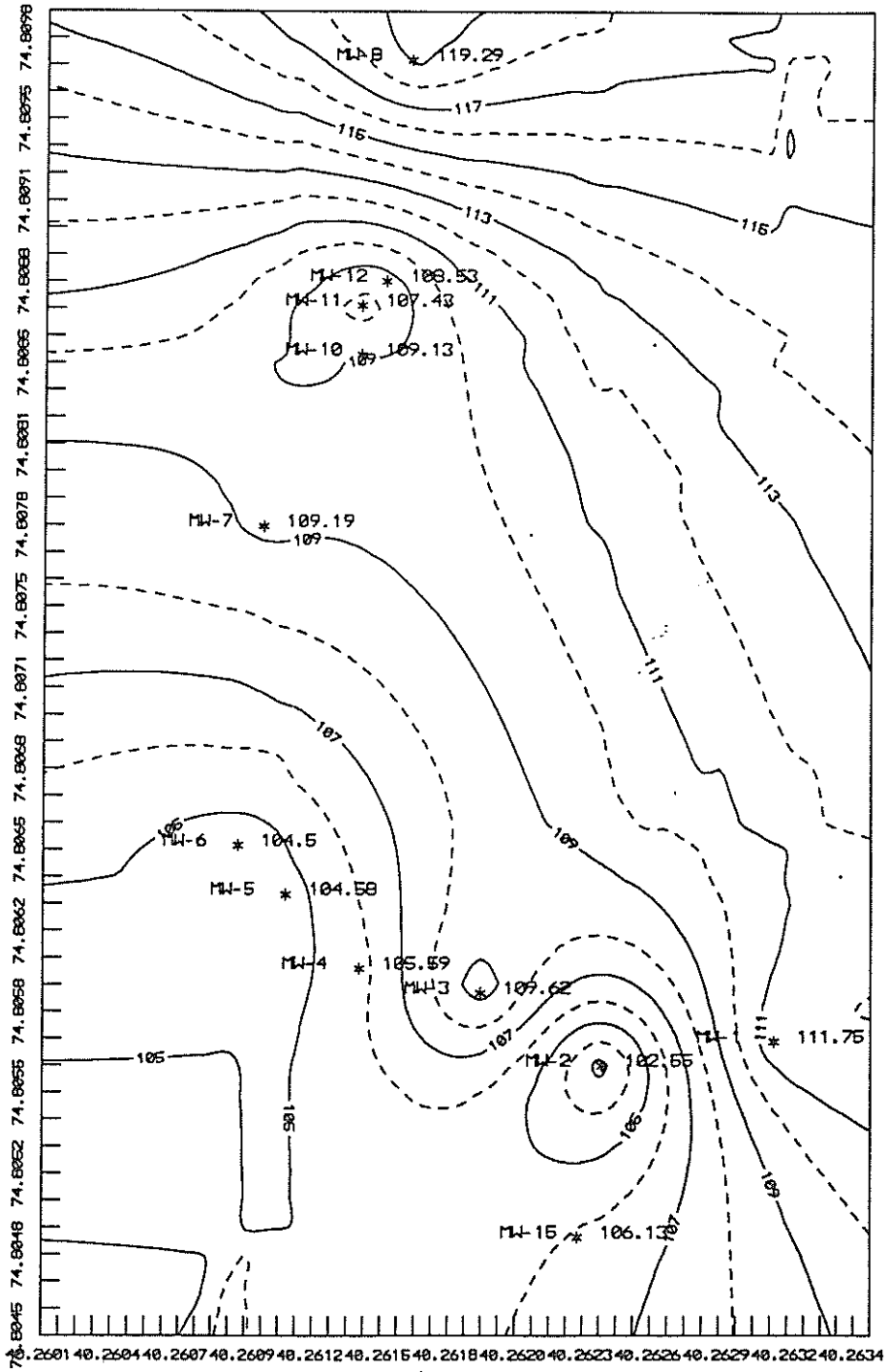


Lawler, Matusky & Skelly Engineers

FIGURE 3-4

IFG-Trenton Groundwater Impact Study

Ground Water Contour Map in Overburden Monitor Wells as measured February 25 1991



Lawler, Matusky & Skelly Engineers

by the program was necessary. Here a southward component to groundwater flow direction has become more apparent. This feature is consistent with the topographic trend for the area, that of decreasing elevation to the southeast.

A definite anomaly in the water table surface is indicated beneath the southeastern corner of the site. It is propagated by the depressed water level (relative to the adjacent wells) in MW-2. To the west and east of MW-2 (at MW-3 and MW-15, respectively) the water table was measured at elevation which are approximately seven feet above competent bedrock. At MW-2 the water table was measured as being less than one foot above the competent bedrock surface. Previous rounds of water level readings are consistent with this result.

A fracture zone or otherwise) highly pervious portion of the bedrock is indicated, a zone which provides a conduit for overburden groundwater either to deepen levels, or simply southward via a channelized flow path in the bedrock surface.

A similar feature is indicated at MW-10, -11, and -12, in that the water table is within approximately one foot of competent bedrock, whereas to the west and east (MW-8 and MW-7, respectively) the water table is between five and ten feet above bedrock.

Figure 3-4a is a hand-drawn water table contour of the same data. This plot agrees closely with Figure 3-4. The flow direction is from northwest to southeast and the above-mentioned anomalies are quite apparent. This figure was prepared to provide an illustration of the competency of the inferences performed by the software package for the southern half of the site. While the details are slightly different, the overall interpretation of the data is consistent between Figure 3-4 and Figure 3-4a.

LMS' review of the existing data on water level measurements, coupled with the continuous water level measurements obtained during our investigation of the interaction of the groundwater system with Gold Run, indicates that there are strong meteorological effects on the occurrence and movement of groundwater in the site's overburden (see Section 3.3). It has been determined, based on LMS' review of IFG's boring logs, water level data, and our field observations made during the installation of the new monitor wells that overburden

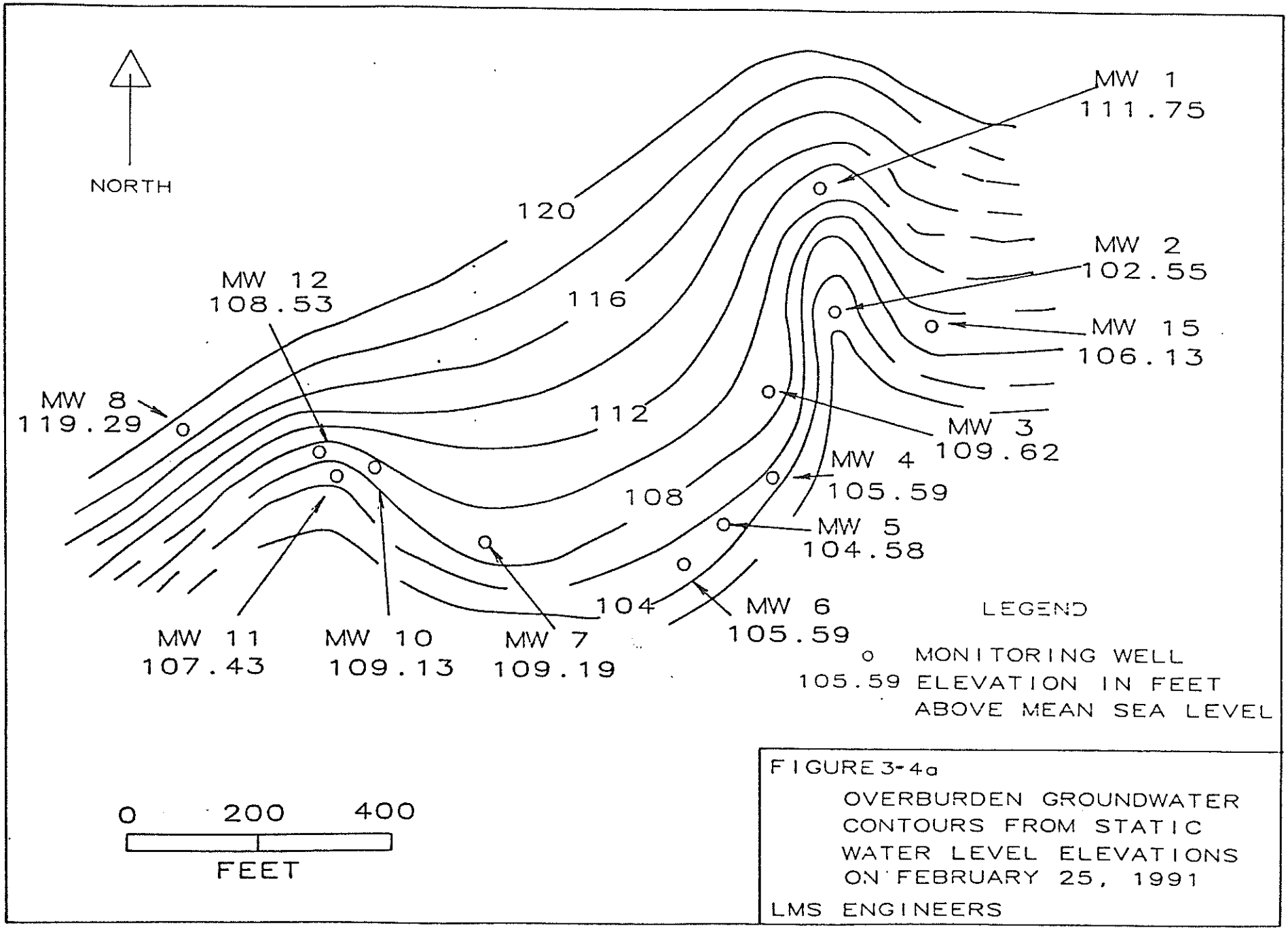


FIGURE 3-4a

OVERBURDEN GROUNDWATER CONTOURS FROM STATIC WATER LEVEL ELEVATIONS ON FEBRUARY 25, 1991

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groundwater flow paths utilize the weathered zone on top of bedrock, as well as the lower portion of the overlying fluvial deposits. This observation implies that there are also strong structural constraints on the occurrence and movement of overburden groundwater. This latter observation is consistent with LMS' interpretations of the site's hydrogeology.

Spatial maps of the average concentration contours of selected compounds in overburden groundwater are provided in Appendix E1. These maps illustrate the spatial distribution of the average concentrations calculated from the measurements of certain metals, semivolatiles, and VOCs. Based on these diagrams, Figures 3-3 and 3-4, and LMS' observations noted above, overburden groundwater has been found to move in discreet pathways and not as a uniform surface. Groundwater in the site's overburden appears to occur and migrate as two channels that flow along the competent bedrock surface towards the south (through the central portion of the site) and towards the southwest corner of the site, respectively. This interpretation is consistent with the observations of previous investigations (Weston 1989b; Weston 1989c). The unexplained subsurface feature in the central portion of the site (noted above) appears to confine and/or direct the occurrence and migration of overburden groundwater.

3.2.2 **Bedrock Hydrogeology**

Widmer (1965) has identified the Stockton bedrock as the only major source of potable groundwater in the county. However, as discussed in Section 1.3.3, naturally occurring (background) concentrations of total dissolved solids (TDS) and other inorganic parameters such as iron, manganese, copper, and barium, as well as the relatively low yields observed for local bedrock wells may restrict its use as an aquifer in the area (Brobst 1965; Degens 1965; Widmer 1965). Based on the observed (average) concentrations of TDS alone (≥500 ppm), groundwater in the Stockton bedrock beneath IFG should be classified as Class GW3 under N.J.A.C. 7:9-6.5 Ground Water Designated Uses and Quality Criteria. N.J.A.C. 7:9-6.5 (d) states that Class GW3 groundwaters "shall be suitable for conversion to fresh potable waters or other beneficial uses." In addition, the average concentrations of manganese (1580.59 ppb), copper (12.52 ppb), and barium (556.67 ppb) in bedrock groundwater (which are expected to be largely attributable to natural background conditions), further limit the

usefulness of bedrock groundwater in the area. These observations may explain why industries in the area (including IFG) use potable waters supplied by the City of Trenton.

Groundwater occurs in the Stockton as a function of the secondary porosity of its sandstone, siltstone, and conglomerate strata. The secondary porosity of these strata is gained from their fractures, joints, and solution cavities, as well as partings along their bedding planes (Weston 1989c; Widmer 1965; Freeze and Cherry, 1979). Well yields in the Stockton have been estimated at a maximum 15 gallons per minute (gpm) (Widmer 1965). However, the observed yields of IFG's bedrock wells have been estimated to be much lower (1-2 gpm).

The potentiometric surface of the bedrock groundwater slopes toward the southeast (Figure 3-5, Figure 3-6; Weston, 1989c). Table 3-1 illustrates the increased head that bedrock groundwater is subject to. These data support the conclusion that the bedrock groundwater occurs under confined conditions (Freeze and Cherry, 1979).

Vertical gradients between the bedrock and overburden groundwater bearing zones have been discerned from the different head measurements obtained from well couplets, e.g. MW-1 and MW-1A (0.03 ft/ft downward), MW-7 and MW-7A (0.08 ft/ft downward) and MW-15 and MW-15A (1.32 ft/ft upward). Driscoll (1986) cites "leaky" confined conditions for some formations. In this scenario, groundwater confined between relatively impermeable strata and subject to greater than atmospheric pressure leaks slowly into or out of the unit via sporadic fractures or intergranular voids. The confining strata are impermeable enough to limit overall groundwater flow upwards under head, but do allow for the transmission of small quantities of water. Based upon our observations, LMS has determined that this type of system is in effect at IFG. This conclusion is supported by the results observed following IFG's dewatering activity in late 1990 and early 1991 (see Section 5.2.1).

It is interesting to note that a transition from a slight downward vertical gradient west of Gold Run to a strong upward vertical gradient east of Gold Run occurs on site. This observation lends support to the inference that Gold Run follows a north-south trending normal fault or extensive fracture system. This zone of increased fractures provides the conduit for bedrock groundwater (under pressure) to rise above the level of groundwater in MW-15. Interaction

TABLE 3-1

WELL DATA FROM SELECTED COUPLETS
ILLUSTRATING CONFINED CONDITION OF
BEDROCK AQUIFER*

WELL	GROUND SURFACE ELEV. (ft)	BEDROCK SURFACE ELEV. (ft)	WELL DEPTH (ft)	SCREENED OR OPEN INTERVAL (ft below grade)	STATIC WATER LEVEL ELEV. (ft)
MW 1	119	-	10	4 - 9	111.75
MW 1A	119	96	40	33 - 40	110.49
MW 7	118	-	16.2	5.5 - 15.5	109.19
MW 7A	118	93 or 98	40	35 - 40	105.45
MW 9	126.5	-	15.5	8 - 15	DRY
MW 9A	126.5	109	40	33 - 40	111.34
MW 15	109	-	13	1.5 - 12	106.13
MW 15A	109	98	28	18 - 28	107.45

*All elevations in feet above mean sea level.

FIGURE 3-5

IFG-Trenton Groundwater Impact Study

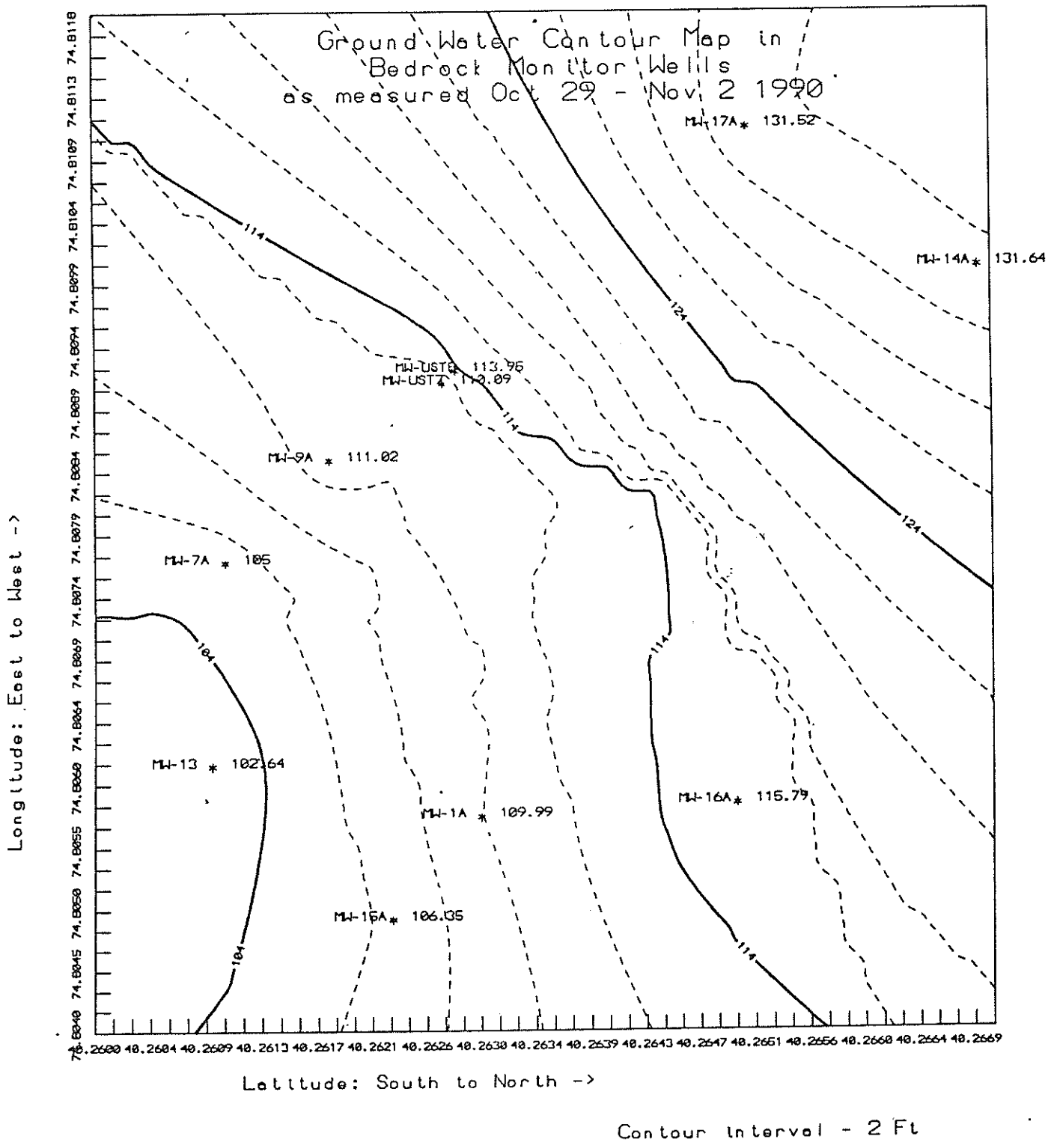

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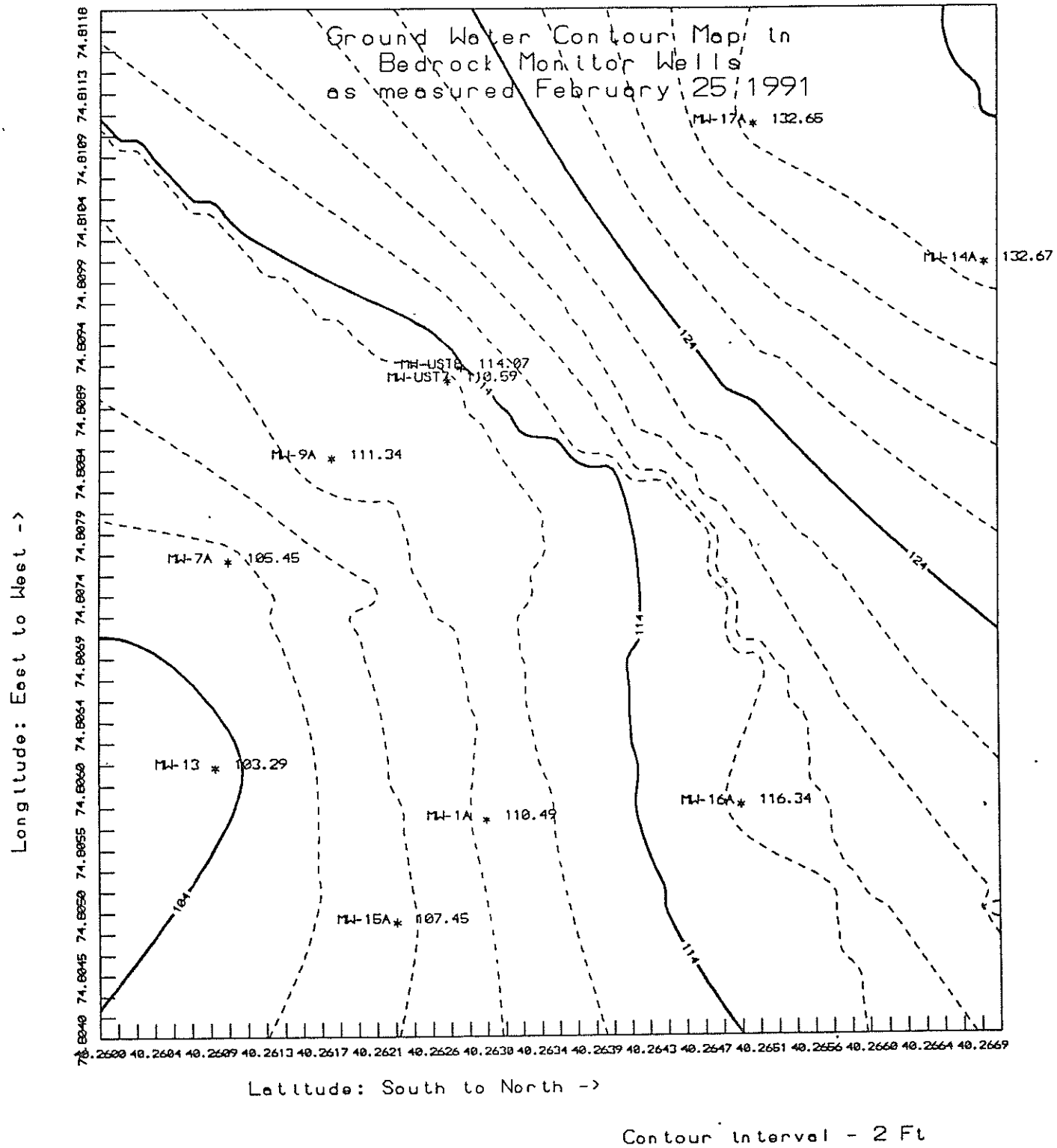
FIGURE 3-6

IFG-Trenton Groundwater Impact Study



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of the bedrock groundwater system with Gold Run was suspected by Weston (1989c), but was unproven until this study. Inasmuch as groundwater in MW15A (adjacent to Gold Run) has at least 16 ft of head and the confined aquifer is a leaky one, interconnection of the bedrock aquifer and Gold Run is implicit.

Observations of locally varying strike/dip in the Stockton and the variation of the Stockton's strike beneath IFG, are indicative of structural deformation (Widmer, 1965). Structural deformation and post-depositional stress-jointing (as is common in Newark Group rocks) of the Stockton may locally enhance its vertical hydraulic conductivity (Widmer, 1965). This jointing probably occurred contemporaneously with the normal faulting of near-surface rock units which commonly occurred in the eastern United States during the Triassic. However, the degree and spatial variation of both lateral and vertical interconnections in the bedrock beneath IFG are not fully known.

Strong hydraulic connection was *not* observed among most bedrock wells during a pump test conducted by Weston (1989b). However, the observed migration onsite of TCE and its degradation products as well as the interconnection between monitor wells UST-2 and UST-8 observed during the pump test (Weston, 1989b), reinforce the inference that some horizontal interconnections exist in the Stockton beneath IFG. In contrast, the observed lack of interconnection of UST-2 with other UST monitor wells during this pump test indicates that there is substantial spatial variation of the degree of interconnection among bedrock wells on site.

Based upon the observed anomalies in the overburden groundwater table and the confined condition exhibited by the bedrock aquifer, a complex hydrogeologic system has been discerned beneath IFG. Overburden groundwater is providing increased head to the bedrock aquifer via discrete, pronounced, generally vertical fractures in the bedrock. The bedrock aquifer is one characterized by isolated permeable sections confined by irregularly-spaced impermeable strata. The variable lateral interconnection within the bedrock aquifer is attributable to the alluvial character of the Triassic Stockton Formation. The meandering nature of sub-aerial net-depositional systems is well documented, and results in a pronounced lateral variation in sedimentary facies. as discovered by the drilling efforts at IGs and

reported by Widmer (1965). The head provided by overburden groundwater undoubtedly is augmented by upgradient elevated offsite reservoirs.

3.3 SURFACE WATER HYDROLOGY

As previously discussed, one of the principal objectives of this project was to evaluate Gold Run as a potentially preferred conduit of contaminant migration. The information available on the Naval Air Propulsion Center (NAPC) suggests that Gold Run is a significant pathway for the migration of contaminants from this upgradient facility onto IFG's property. Therefore, the field program described in Section 2.3 was designed to examine Gold Run's influence on local groundwater flow and contaminant migration.

3.3.1 Field Observations

During the installation of the Stevens recorders in Gold Run, LMS noted that the stream runs close to or directly on top of the fractured Stockton Formation bedrock. The stilling wells' vertical stabilizers made it easy to determine the depth to the top of rock (refusal) at each location. Less than 1 ft of loose sediments were encountered above rock at the locations of SW-16A and SW-15. Gold Run was quite shallow (6 in. to 2.5 ft deep) at these locations. Weathered slabs of Stockton sandstone and shale were observed to outcrop along and within the reaches of Gold Run adjacent to SW-16A and SW-15. The wedge of unconsolidated stream sediments near SW-13 appeared to be slightly thicker (≈1-1.5 ft). Gold Run was observed to be wider and deeper at SW-13. The locations of each of the stilling wells are shown on Figure 1-2.

LMS' desktop analyses of the available site plans for IFG, (as well as the surveyed elevations of monitor wells on both sides of Gold Run), raised the possibility that Gold Run follows the path of a north-south trending normal fault. IFG's site plans show the ground surface elevation west of Gold Run to be consistently higher than that east of the stream. The presence of this possible fault was noted by LMS in the field. The feature appeared most prominent when looking north along Gold Run from the concrete bridge just south of the

pond (Figure 1-2). It is common for streams to develop along fault planes, where sediment fill or brecciated rock present in the fault provides a zone of preferential erosion.

3.3.2 Continuous Water Level Measurements and Hourly Precipitation Data

3.3.2.1 *Continuous Water Level Measurements.* As previously discussed, LMS deployed three pairs of Stevens recorders at IFG from 28 November to 27 December 1990. Stevens recorders use mechanical wheel and float assemblies to continuously measure water level changes. In a typical Stevens recorder installation, the float installed in a given monitor well or stilling well moves up and down according to the corresponding fluctuation in the water level. The vertical movement of the float causes a comparable rotation of the mechanical drum in the recorder box, upon which rests a graph paper chart and a pen. The pen is moved across the chart paper on the drum at a rate determined by the user-selectable period of observation (in this case eight days). Therefore, the vertical change in water level over time is permanently recorded by the trace of the pen on the chart paper.

Rosenberry (1990) compared long-term groundwater level measurements obtained with both mechanical-float systems (such as Stevens recorders) and electrical pressure transducers. The continuous water level measurements obtained with mechanical-float systems were shown to produce less error than those obtained with electrical pressure transducers when both were periodically checked with hand measurements (Rosenberry, 1990). The error of the mechanical-float systems was attributed to their total internal friction, which caused them to lag rapid changes in water levels. The subsequent "lag" errors in the water level data recorded by mechanical-float systems were both predictable and correctable (Rosenberry, 1990). By comparison, the error observed in measurements obtained with electrical pressure transducers appeared random and therefore not correctable (Rosenberry, 1990).

3.3.2.2 *Hourly Precipitation Data.* November and December 1990 precipitation data for the local area were obtained from the National Climatic Data Center. These data consist of the hourly amounts of precipitation recorded at a Fischer-Porter Gage station at Trenton State College. The original data were converted to precipitation rates for their corresponding time

intervals in a spreadsheet. Each hourly rate value was averaged with the next to calculate the anticipated precipitation rates on a 0.5-hr basis.

3.3.2.3 *Data Reduction.* The water level measurements recorded on each of the Stevens recorder charts from the study at IFG were "picked" at 0.5-hr intervals and transferred to a Quattro Pro spreadsheet. The surveyed elevations of the monitor wells and stilling wells were used to "truth" the water level measurements in the spreadsheet to their corresponding water level elevations. Consequently, time-series of the water levels (or continuous static head) for each of the stations were produced and subsequently plotted (Appendix F). The anticipated "lag" error present in the data was assumed to be the same for each station, and therefore attempts were not made to apply a correction factor to the data set. However, for purposes of this investigation, the average measurement error (±0.027 ft) anticipated for the data is not expected to be important (Rosenberry, 1990).

3.3.3 Data Analysis and Interpretation

The periods of observation from which usable data were obtained from each Stevens recorder are shown in Table 3-2. Basic statistical information, such as the minimum, maximum, average, standard deviation, and observed range in water elevations were calculated from each time-series of data and are also provided in Table 3-2.

Several storm events were observed during the deployment of the Stevens recorders at IFG. Significant differences in the responses to these storm events were recorded at different locations. As shown on Table 3-2, MW-16A showed the highest recorded water level elevation (118.95 ft on 4 December 1990), and SW-13 showed the lowest (102.21 ft on 17 December 1990). SW-13 also showed the greatest range of water level elevations (3.72 ft). By comparison, the smallest range of water level elevations (0.54 ft) was observed in SW-16A adjacent to MW-16A. The highest standard deviation in the water level measurement data (≈0.72 ft) was observed for MW-16A, and the lowest standard deviation (0.082 ft) was observed for SW-16A.

Table 3-2
Summary of Statistics: Continuous Water Elevation Measurements

INFORMATION		ALL	MW-16A	SW-16A	MW-15	SW-15	MW-13	SW-13
PERIOD OF	*FROM:*	---	0900 11/29	1500 11/28	1630 11/28	1430 11/29	1600 11/28	1330 12/10
OBSERVATION	*TO:*	---	2000 12/26	1030 12/27	1600 12/26	1030 12/27	0600 12/26	1130 12/20
	MINIMUM	102.21	115.67	115.76	106.20	105.48	102.62	102.21
	MAXIMUM	118.95	118.95	116.30	107.37	107.43	103.75	105.93
	RANGE	16.74	3.28	0.54	1.17	1.95	1.13	3.72
	AVERAGE	109.09	116.66	115.89	106.64	105.58	102.98	102.65
	STD	5.79	0.72	0.08	0.30	0.17	0.26	0.45

NOTE: All values are in feet above mean sea level

3.3.3.1 *Hydrographs*. Two sets of hydrographs were generated from the data discussed above. The first set of hydrographs compares the entire time-series of "head" measurements obtained from each monitor well and its corresponding stilling well. These hydrographs illustrate the relationship of the total groundwater head to the surface water head over time at each station. Therefore, information such as whether Gold Run is "gaining" water from the groundwater system at a given station can be inferred (Appendix F).

The second set of hydrographs compares the time-series of head data from each individual recorder to the time-series of precipitation rate data by plotting each against its own y-axis (Appendix F). These hydrographs illustrate the response of the groundwater and surface water systems (as measured by each Stevens recorder) to storm events.

3.3.3.2 *Summary of Observations: MW-16A and SW-16A*. MW-16A and SW-16A are located near the northernmost reach of Gold Run present within IFG. As previously discussed, the highest head measurement was recorded at MW-16A (118.95 ft on 4 December 1990), which also showed the highest standard deviation in its data (≈0.72 ft). By comparison, the smallest range of water level elevations was observed in SW-16A adjacent to MW-16A (0.54 ft), which also showed the lowest standard deviation (0.082 ft). The head in MW-16 (average = 116.66 ft) exceeded that observed in SW-16A (average = 115.89 ft) for the majority of the period of observation. However, the opposite situation occurred during the first few days (28 November-4 December) as well as for a short time on 15 December. The comparison hydrograph for MW-16A and SW-16A suggests that the surface water head may exceed that in the bedrock groundwater at this location during prolonged dry periods; consequently, Gold Run may provide recharge to the bedrock groundwater system to its west during prolonged dry spells. However, each storm event was observed to quickly reverse this situation.

Total head in MW-16A was found to increase quickly (within 3 hrs) and substantially (1.5 to ≥3 ft) in response to storm events, and dissipate slowly (≥12 days). By contrast, head in Gold Run (as measured at SW-16A) was found to respond instantaneously to storms and re-equilibrate quickly (≤1 day), although the changes in total head observed are not substantial (≤0.5 ft).

The response of MW-16A to a storm that began late 3 December is dramatic, as illustrated by the rapid rise in total head from its lowest observed (115.67 ft) to its highest (118.95 ft) over a period of approximately 6 hrs. By contrast, the dissipation of the storm-induced head observed in MW-16A occurred slowly and asymptotically (≥12 days to decrease to ≈115.9 ft prior to another storm on 15 December). The response (instantaneous) and re-equilibration (≤1 day) of the water level in SW-16A were both more rapid, although the head observed at SW-16A only changed by ≈0.5 ft. The responses of MW-16A and SW-16A to later storms were similar. Comparison of the hydrographs for MW-16A and SW-16A, as well as the information noted above, suggests that little hydraulic connection between Gold Run and the shallow bedrock groundwater system exists at this location. This conclusion supports LMS's contention that the bedrock aquifer is subject to leaky confined conditions.

3.3.3.3 *Summary of Observations: MW-15 and SW-15.* MW-15 and SW-15 are located adjacent to and within the central reach of Gold Run at IFG, respectively. The observed ranges in their water level elevations were similar: 1.17 ft for MW-15, and 1.95 ft for SW-15. Both MW-15 and SW-15 exhibited rapid (near-instantaneous) responses to storms. The hydrographs for both MW-15 and SW-15 show greater "short-term" fluctuations over the duration of the storm events than were observed for their upstream counterparts.

Comparison of the hydrographs of MW-15 and SW-15 suggests that significant interaction between the overburden groundwater and Gold Run occurs in this area, as indicated by their similar (initial) responses to storm events and their comparable ranges of water level fluctuations observed during this investigation. Head in MW-15 (average = 106.64 ft) was observed to almost always exceed that in SW-15 (average = 105.58 ft) by ≥1 ft, which suggests that discharge of overburden groundwater to Gold Run along its east bank typically occurs at this location. However, head in SW-15 spiked higher than that in MW-15 during a brief period of intense rainfall on 18 December.

3.3.3.4 *Summary of Observations: MW-13 and SW-13.* MW-13 and SW-13 are located near the southeast corner of IFG's property. SW-13 was located ≈100 ft southwest of MW-13 because of difficult field conditions (as opposed to the other monitor well/stilling well pairs, which are at nearly identical latitudes along their respective reaches of Gold Run).

Therefore, the ground elevation at MW-13 may be slightly higher than that immediately adjacent to SW-13. This may be important, as the average water levels observed in MW-13 (102.98 ft) and SW-13 (102.65 ft) were the closest of the three stations investigated. By comparison, the ranges of water level elevations observed in MW-13 and SW-13 were quite different (1.13 ft and 3.72 ft, respectively). The observed ranges in water level elevations at this location were the lowest measured in groundwater and the highest measured in Gold Run, respectively.

Groundwater interaction with Gold Run appears the most complicated at this location. Significant spikes (≥3 ft changes) in the head measured in SW-13 were observed during storms over its period of record (10-20 December). The head observed in Gold Run at SW-13 exceeded that in MW-13 by ≈1.5-2.5 ft during four brief storm periods. This observation suggests that during storm events, groundwater discharge from Gold Run to the overburden along the east bank occurs.

3.3.4 Interaction of Gold Run With the Shallow Groundwater System

From the observations noted above, significant differences in the degree of interaction between Gold Run and groundwater appear to occur along two of the three reaches investigated. Groundwater interaction with Gold Run appears to become increasingly complicated from north to south. This conclusion is supported by the following observations:

- The range of water level elevations measured in Gold Run increased from north-to-south. A corresponding north to south increase in the standard deviations of the water elevation data from Gold Run was also observed.
- In contrast, the range of water levels measured in groundwater decreased from north to south, as do the corresponding standard deviations of these measurements.
- The difference between the average head observed in groundwater and that in Gold Run decreases from north to south. This suggests that the groundwater and surface water systems are approaching greater equilibrium from north to south.

Given the observations noted above, the inferred increase in groundwater-surface water interaction from north to south is to be attributed to an increase in the net discharge of groundwater to Gold Run. The concentrations of contaminants attributed to off-site sources (e.g., TCE, 1,2-DCE, and vinyl chloride), also show a comparable increase from north to south. These observations suggest that the southernmost area of Gold Run near SW-13 and MW-13 is an important groundwater discharge zone for this area (see Chapter 4).

In conclusion, these observations support the hypothesis that Gold Run behaves as a preferred conduit for surface water contaminant migration, especially with respect to TCE and its degradation products. While Gold Run itself appears to be an important pathway for contaminant migration, it also appears have a controlling influence during storm events on overburden groundwater movement east of IFG's former sludge impoundments. A north-south trending fault or fracture system in the Stockton bedrock beneath Gold Run is suspected to be the controlling mechanism for such flow and contaminant migration.

However, the presence of TCE and DCE in MW15A, on the west bank of Gold Run, indicates that there is lateral interconnection in bedrock below Gold Run. This aspect is treated further in Chapter 5.

3.4 ADDITIONAL OBSERVATIONS

The natural response of the bedrock groundwater observed at MW-16A and MW-13 shown by their hydrographs (as well as the overburden groundwater observed at MW-15) closely resembles Aron-Scott discharge-time diagrams typically used for the evaluation of pump test data (Kruseman and de Ridder, 1983). Both the hydrographs and the Aron-Scott discharge-time diagrams mentioned above illustrate the non-linear decrease in head and discharge rate of pumped groundwater systems over time, respectively. Therefore, further analysis of the water level data obtained during this investigation may yield realistic calculations of the transmissivity (to 5-10% accuracy) and the storage coefficient (to 20-30% accuracy) in the overburden and bedrock groundwater zones at IFG along Gold Run (Kruseman and de Ridder, 1983). This information would be important for the design of an effective remedial strategy for the sludge impoundment area.

CHAPTER 4

SUMMARY OF GROUNDWATER QUALITY DATA

As previously noted, quarterly sampling and analysis of groundwater has been performed since 1986 at IFG in accordance with the conditions of IFG's NJPDES/DGW permit. IFG's groundwater chemistry data reports for their DGW sampling conducted by LMS in October-November 1990 are provided in Appendix G.

LMS performed the statistical analysis of a database that contains IFG's historical groundwater quality data since 1987. Relatively complete records were available only for IFG's NJPDES/DGW monitor wells from 1987 to date; therefore, the database does not contain information on the UST wells. In addition to these statistical analyses, spatial contour maps (Appendix E1) and temporal variation diagrams (Appendix E2) of selected parameters and monitor wells were prepared.

4.1 STATISTICAL ANALYSES

To facilitate the timely and effective analysis of the historical groundwater quality data at IFG, LMS first constructed a master database of the existing data through October 1990. This database was constructed in Borland's *Paradox*. In addition to IFG's historical groundwater data, this database includes pertinent information on the construction of their NJPDES/DGW monitor wells. Subsequently, LMS performed "basic" statistical analyses of this data (e.g., calculations of means, maximums, minimums, and standard deviations).

4.1.1 Basic Statistical Analysis

The database referenced above was used to generate basic statistical information on the historical groundwater quality at IFG. The mean, maximum, minimum, and standard deviation of the values for a given parameter over the entire record were calculated and printed out in three different ways as described below:

1. Statistics for each well, by parameter
2. Statistics for each parameter, by well
3. Statistics for each parameter in all bedrock wells and all overburden wells

The printed summaries of the information described above are included in Appendix H. A summary of the statistical information generated from approach (1), which includes information on only those parameters that were detected in a given monitor well, is provided in Table 4-1. Although the statistical information provided in Appendix H and summarized in Table 4-1 is useful as a management tool, it is limited by the number of total records ($\leq$13) for each parameter in the database (Davis, 1986).

4.1.1.1 *Treatment of "Nondetected" Values in Basic Statistical Analyses.* In terms of the generation of the statistical information described above, an important assumption needs to be explained. Because a large number of raw values in the database were reported as "nondetected" (ND) or "below the detection limit" (BDL), LMS treated all such values as = 1/2 the reported detection limit (DL). Although the assumption to set ND values = 1/2 DL is arbitrary, it is a conservative option commonly used and recommended by regulatory agencies for the statistical analysis of groundwater quality data such as that described above (EPA, 1986). In addition, this treatment of ND values is consistent with that used to calculate IFG's NJPDES/DGW permit fee. However, in the review of the statistical information provided in Appendix H and Table 4-1, the effect of this assumption on the means and standard deviations reported for a given parameter should be recognized. This is especially important for certain parameters and/or wells where most if not all of the values reported in the raw data are NDs. Furthermore, the detection limits (DL) of most parameters have changed one or more times over the course of IFG's NJPDES/DGW groundwater monitoring program. To help evaluate the effects of ND values on the statistical information provided in Appendix H, both the information in Appendix H and Table 4-1 provide information on the total number of analyses and the total number of reported ND (or "BDL") values. Therefore, the total number of reported values above the DL for each parameter by well and/or groundwater-bearing zone (overburden or bedrock), can be evaluated relative to the number of total analyses, NDs and the statistical information provided.

4.2 SPATIAL DISTRIBUTION OF SELECTED PARAMETERS

As discussed in Chapter 3, LMS produced spatial contour maps of the average values calculated for selected parameters in **both** overburden and bedrock monitor wells at IFG (Appendix E1). A description of the methods and parameters selected for these diagrams, as well as the basis for their interpretation is provided in the following sections.

4.2.1 Map Preparation

Spatial contour maps of the parameters listed above were produced by LMS with a commercially available software package (*Surfer*). These spatial maps plot the average value of a given parameter in each well as a simple x (latitude), y (longitude), and z (parameter value) data point. The x and y coordinates in these maps are decimal fractions of the surveyed latitude and longitude of the monitor wells, respectively, and do not change. Therefore, these maps are "not to scale" in as much as units of latitude and longitude are not equal at the longitude and latitude of IFG. Units of latitude do not change with respect to position on the globe; however, units of longitude correspond to a cosine function of the latitude at a given location. At IFG, the ratio of units of longitude to those of latitude is approximately 0.771 to 1. Therefore, the longitude axis of each spatial map is exaggerated by a factor of approximately 1.3 (i.e. 1/0.771). However, it should be noted that this exaggeration of the longitude axis is merely aesthetic, and has no effect on the mathematics used to generate contours among data points (see below).

4.2.2 Spatial Interpolation

Interpolation between data points was performed in *Surfer* by *kriging*. Kriging is a technique commonly used to perform the spatial interpolation of geologic data (Matheron, 1965; Journel and Huijbregts, 1978; Watson, 1984; Davis, 1986). Kriging employs a "predictor" function to conduct the non-arbitrary interpolation among data points. The kriging predictor function is based on the performance of specific matrix operations on the original data. Subsequently, interpolation between actual data points is performed with this predictor function. Kriging theory helps compensate for (and therefore minimize) interpolation error by taking into

account both variance and covariance effects in the determination of the predictor function. See Matheron (1965), Journel and Huijbregts (1978), Watson (1984) and Davis (1986) for more thorough discussions of kriging theory.

The accuracy of the values supplied by this predictor function is dependent on the accuracy of the original data. Consequently, errors in data collection, analysis, or reporting in the original data set may lead to errors in the values returned by the predictor function for the parameter being described.

4.2.3 Assumptions and Effects of Data Interpolation by Kriging

Kriging is considered one of the most reliable techniques in the spatial interpolation of geologic data. While interpolation by Kriging produces theoretically accurate results, the spatial distribution of subsurface geologic characteristics is typically nonuniform (Davis, 1986). Therefore, the limited number of available data points, (as well as the software settings used to generate the kriging predictor function for a given parameter), inevitably provides for the propagation of error. Given the spatial variation observed in the fluvial overburden sediments at IFG, and the inferred structural complications of both the fractured and competent bedrock zones beneath the site, the number of "usable" data points for the overburden (12) and bedrock (8) complicates their interpolation and interpretation. However, the errors introduced by the inherent limitations of the available data were consistent, as the software settings used to create each overburden and bedrock spatial plot were the same, respectively. The software settings used to create the *Surfer* plots for each parameter are described below:

Grid density:	50 x 50
Interpolatation:	Kriging
No. nearest neighbors:	Overburden (5) and bedrock (4)

Note: For Figures 3-1 and 3-2, the number of nearest neighbors selected was 10 (out of 23 total data points).

Attention may be drawn to contour lines on these maps that do not seem "intuitively correct." These values most often appear on the perimeter of the maps, as the tendency of kriging is to extend the surface in whatever direction it is propagating. Software-related "artifacts" in

the maps may also be attributed to "nugget" effects, where the selected number of nearest neighbors chosen in a given subarea of the map may be too small to provide enough outlying data points for adequate interpolation. However, while it is important to understand the limitations discussed above, kriging is considered to be far superior to other methods of data interpolation for applications such as those presented herein.

4.2.4 **Interpretation of Spatial Contour Maps**

The spatial contours of a given chemical parameter can be interpreted in several ways. First, the average concentration of a chemical parameter for the referenced time period is provided next to the asterisk which denotes the location of a given monitor well. Second, the contour lines among data points provide information on the "shape" and direction of flow. This information forms the basis for the investigation of the source and migration of a given parameter.

Three sets of selected parameters were chosen for investigation of spatial distribution in both overburden and bedrock groundwater. These parameters were chosen based on LMS' initial review of the groundwater quality data within the context of the groundwater issues discussed Chapter 1.. The selected "target" parameters include the following:

(1) *Metals*: arsenic, copper, nickel, and zinc

(2) *Semivolatiles*: acenaphthene, naphthalene, bis(2-ethylhexyl)phthalate, 1,2,4-trichlorobenzene, 1,4-dichlorobenzene, and chlorobenzene.

(3) *Volatile organic compounds (VOCs)*: benzene, methylene chloride, TCE, 1,2-trans-DCE, and 1,1,1-TCA

A discussion of the spatial distribution of these groups of selected chemical parameters is provided in the following sections.

4.2.5 Spatial Distribution of Selected Parameters in Overburden Groundwater

4.2.5.1 *Selected Metals in Overburden.* Arsenic is found at greater average concentrations to the west than the east, with the highest observed in MW-8 (22 ppb); however, the reported "average" for MW-8 is based on only one analysis, as this well is typically dry. The second highest average concentration of arsenic was observed in MW-4 (9 of 13 values ≥DL; 9.36 ppb average), just east of former sludge impoundments.

Copper was observed at its highest average concentrations in MW-11 (13 of 13 values ≥DL; 84.89 ppb average) and MW-8 (1 of 1 values ≥DL; 70 ppb "average"). With the exception of the values observed at MW-11, the spatial distributions of copper and arsenic in overburden groundwater do not suggest that an isolated source area exists for these metals on site. These maps suggest that their distributions are related in part to upgradient sources and/or natural background conditions.

The spatial maps for nickel and zinc show that the monitor wells around the eastern and southern perimeter of the former sludge impoundments contain the highest average concentrations of nickel and zinc. The relative hot spots of these metals in eastern perimeter monitor wells are MW-2 (Ni--9 of 13 values ≥DL; 37.69 ppb average, Zn--12 of 13 values ≥DL; 651.46 ppb average), MW-4 (Ni--10 of 13 values ≥DL; 135.62 ppb average, Zn--6 of 13 values ≥DL; 24.5 ppb average), MW-5 (Ni--13 of 13 values ≥DL; 496 ppb average, Zn--9 of 13 values ≥DL; 35.69 ppb) and MW-6 (Ni--6 of 13 values ≥DL; 32.38 ppb average, Zn--7 of 13 values ≥DL; 40.15 ppb).

The monitor wells located to the south-southwest of the former impoundments also show occasional to consistent elevated concentrations of nickel: e.g. MW-7 (13 of 13 values ≥DL; 491 ppb average) MW-11 (5 of 13 values ≥DL; 24.41 ppb average) and MW-12 (9 of 13 values ≥DL; 27.69 ppb average). Zinc is also commonly detected in these wells: e.g MW-7 (12 of 13 values ≥DL; 331 ppb average), MW-11 (9 of 13 values ≥DL; 55.93 ppb average) and MW-12 (12 of 13 values ≥DL; 246.85 ppb average).

The spatial maps for nickel and zinc suggest that the former sludge impoundments are the probable sources of a plume of these metals in the overburden groundwater, which is reflected in the values reported for wells MW-2, MW-4, MW-5, and MW-6 those on the eastern and southern perimeter of the impoundments. The relatively consistent occurrence of these metals at elevated concentrations in MW-7, MW-11 and MW-12 as well as that of copper in MW-11 can most likely be associated with onsite activities related to metal plating.

Copper and nickel were also detected in MW-15, east of Gold Run, at concentrations of 37 ppb and 15 ppb, respectively, in the only sample of record (October 1990). Insufficient information is available to determine whether the presence of these metals in MW-15 is attributable to upgradient or on-site sources.

4.2.5.2 *Selected Semivolatiles in Overburden.* Acenaphthene and 1,2,4-trichlorobenzene show nearly identical distributions in overburden groundwater; however, they have typically not been measured above the detection limit in most overburden monitor wells. Therefore, the spatial distribution maps of their "average" distributions in overburden groundwater are based largely on numbers generated from 1/2 DL values in the database (Appendix H). The contours of both of these compounds lead to a "value" of 25 ppb at MW-15, which is an artifact of the higher detection limit for these compounds in recent laboratory analyses--both were not detected in the October 1990 sample from MW-15. Therefore, given the typically widespread absence of these compounds, their spatial distribution maps are of little use.

Acenaphthene has been detected above the DL only 10 out of 123 total analyses in overburden groundwater (Appendix H). MW-5 (5 of 13 values ≥DL; 7.63 ppb average) and MW-7 (5 of 13 values ≥DL; 6.92 ppb average) account for all of the observed "hits" of acenaphthene (Table 4-1). Similarly, 1,2,4-trichlorobenzene has been measured above the DL in only 5 of 124 total analyses. Likewise, two monitor wells, MW-3 (4 of 13 values ≥DL; 8.46 ppb average) and MW-10 (1 of 13 values ≥DL; 7.3 ppb "average"), account for all of the "hits" of 1,2,4-trichlorobenzene. Therefore, these compounds do not appear to be a concern in the overburden groundwater at IFG.

As with the spatial maps for acenaphthene and 1,2,4-trichlorobenzene, the map for bis(2-ethylhexyl) phthalate appears to be largely related to artifacts of the data analyses. In addition, bis(2-ethylhexyl) phthalate is a very common field and laboratory contaminant, (i.e. from the handling of samples with latex gloves and plastic ware). Therefore, it is difficult to determine the extent to which the calculated averages used to generate this spatial map are attributable to site conditions.

Bis(2-ethylhexyl) phthalate has been reported above the DL in 39 out of 122 total analyses of overburden groundwater. The "outlying" measurement of bis(2-ethylhexyl) phthalate at 1900 ppb in MW-15 in October 1990 was coincidental with its detection in the method blank. Therefore, this value is not considered reliable; consequently, the spatial map for bis(2-ethylhexyl) phthalate should be considered "artificial," as this suspect value dominates the trend of the contours.

Naphthalene has been measured above the DL in 25 out of 122 total analyses of overburden groundwater (Appendix H). As noted above for nickel and zinc, naphthalene is predominantly detected in the monitor wells around the eastern and southern perimeter of the former sludge impoundments: MW-4 (2 of 13 values ≥DL; 7.12 ppb average), MW-5 (11 of 13 values ≥DL; 29.94 ppb average) and MW-6 (1 of 13 values ≥DL; 7.12 ppb average). MW-7 also shows consistent hits of naphthalene (11 of 13 values ≥DL; 53.82 ppb average) (Appendix H; Table 4-1).

Chlorobenzene has been measured above the DL in 48 out of 123 total analyses (Appendix H). Chlorobenzene shows a similar distribution in the monitor wells around the eastern perimeter of the former impoundments: e.g. MW-4 (8 of 13 values ≥DL; 10.67 ppb average), MW-5 (13 of 13 values ≥DL; 32.86 ppb average) and MW-6 (12 of 13 values ≥DL; 71.18 ppb average). As noted above for naphthalene, MW-7 also shows consistent hits of chlorobenzene (13 of 13 values ≥DL; 69.08 ppb average).

The consistently high values for naphthalene and chlorobenzene measured at MW-7 suggest that another onsite source, probably one related to fueling and/or oiling activities was once or is still present. 1,4-dichlorobenzene has been measured above the DL in 15 out of 132

total analyses of overburden groundwater (Appendix H). Although the spatial distribution of 1,4-dichlorobenzene appears to be different from that described above for naphthalene and chlorobenzene, it is also most commonly detected in the monitor wells to the east-southeast of the impoundments. 1,4-dichlorobenzene is most commonly detected in MW-4 (7 of 14 values ≥DL; 16.04 ppb average), MW-5 (4 of 14 values ≥DL; 9.78 ppb average) and MW-6 (2 of 14 values ≥DL; 8.18 ppb average). 1,4-dichlorobenzene is only detected above the DL once in MW-7 (7.25 ppb "average") to the south of the impoundments. The spatial contours for 1,4-dichlorobenzene show a strong east-southeast trend, towards the inferred discharge zone along Gold Run (see Chapter 3). However, this trend may be related to an artifact of the "average" value shown for MW-15 (15 ppb), which is equal to 1/2 the DL reported for the October 1990 analysis.

Based on the available information on the historical operations at IFG (Appendix A) and chemistry of the sludge (Appendix B), the semivolatiles selected for spatial analysis are suspected to be related to (1) the sludge impoundments and (2) a source upgradient of MW-7, possibly related to activities involving petroleum hydrocarbons.

4.2.5.3 *Selected VOCs in Overburden.* Methylene chloride and benzene both show distributions in overburden groundwater that are similar to the bifurcated plumes noted above for nickel, zinc, naphthalene, and chlorobenzene. These VOCs are most commonly detected in the overburden wells around the eastern and southern perimeter of the former impoundments (Table 4-1). Benzene has been measured above the DL in 38 out of 124 total analyses of overburden groundwater samples (Appendix H). By comparison, methylene chloride has been measured above the DL in 19 out of 124 total analyses of overburden groundwater (Appendix H).

Benzene is commonly detected in MW-5 (12 of 13 values ≥DL; 12.67 ppb average), MW-6 (12 of 13 values ≥DL; 18.05 ppb average) and MW-7 (11 of 13 values ≥DL; 17.58 ppb average). Benzene is occasionally detected at trace levels in MW-4 (3 of 13 values ≥DL; 1.42 ppb average). The former UST area is expected to be the primary source of benzene and other gasoline-related aromatics.

Methylene chloride is less commonly detected than benzene in overburden monitor wells. Methylene chloride is found at generally lower (trace) concentrations than benzene, and in monitor wells farther to the north as well: e.g. MW-2 (3 of 13 values ≥DL; 1.78 ppb average), MW-3 (3 of 13 values ≥DL; 1.47 ppb average), MW-4 (1 of 13 values ≥DL; 1.42 ppb average), MW-5 (3 of 13 values ≥DL; 3.37 ppb average), MW-6 (1 of 13 values ≥DL; 1.52 ppb average) and MW-7 (3 of 13 values ≥DL; 1.68 ppb average).

Methylene chloride is a common laboratory solvent, and has frequently been reported with "J" (estimated concentration/below quantification limit) and "B" (found in method blank) qualifiers in the laboratory reports for IFG's DGW sampling program (e.g. October 1990 reports for MW-5 and MW-7; Appendix G). Since the average values listed for these overburden monitor wells are below the current method 624 GC/MS quantification limit (≈5 ppb), methylene chloride should not be perceived as a problem with respect to the impoundments.

TCA has also not been commonly reported at levels above the DL in overburden wells around the perimeter of the impoundments (7 hits above the DL out of 124 total analyses; Appendix H). The highest average value of TCA (based on more than one "hit") is reported for MW-10 (2.49 ppb; Appendix H, Table 4-1). However, TCA has been detected above the DL in MW-10 in only three out of 10 analyses (Table 4-1). Therefore, TCA should not be perceived as a problem in overburden groundwater at IFG.

TCE and its degradation products, 1,2-trans-DCE and vinyl chloride, are the most prevalent VOCs in overburden groundwater at IFG (Appendix H). TCE has been measured above the DL in 48 out of 128 total analyses of overburden groundwater, while DCE has been measured above the DL in 58 out of 123 total analyses. Vinyl chloride has been much less commonly detected in overburden groundwater (9 out of 123 total analyses; Appendix H).

TCE and 1,2-trans-DCE were chosen for spatial analysis. The spatial plots of both TCE and DCE illustrate a south/southeast bifurcated plume of these compounds that originates off site. The shape of the contours for both of these compounds suggests that Gold Run exhibits a significant influence on their distribution. The highest "average" concentrations of both TCE

and DCE occur in the only sample of record (October 1990) for MW-15 east of Gold Run (110 ppb and 30 ppb, respectively; Table 4-1).

TCE and DCE have not been detected in overburden monitor wells MW-4, MW-5, MW-6 and MW-7, which typically show the highest concentrations of compounds attributed to the sludge impoundments. This observation further supports the presence of an off-site source of these compounds (NAPC). In addition, the common occurrence of TCE and DCE in overburden groundwater north and west of these wells further suggests that a bifurcation of overburden groundwater flow occurs on site (Chapter 3).

4.2.6 Spatial Distribution of Selected Parameters in Bedrock Groundwater

4.2.6.1 *Selected Metals in Bedrock.* Arsenic is typically not detected in bedrock groundwater--i.e. it has only been measured above the DL in 7 out of 45 total analyses. Arsenic has been detected above the DL twice in upgradient well MW-1A (2 of 13 values ≥DL; 2.58 ppb average), as well as MW-7A (2 of 13 values ≥DL; 2.55 ppb average) and MW-9A (2 of 13 values ≥DL; 2.81 ppb average). Arsenic was detected once in MW-13 (2.32 ppb "average"). The spatial map of arsenic in bedrock groundwater suggests that background and/or off-site influences on its distribution exist. In addition, Gold Run appears to have a controlling influence on its spatial distribution.

Copper has only been measured above the DL in 6 out of 45 total analyses of bedrock groundwater. Copper was detected once in upgradient bedrock well MW-14 (1 of 3 values ≥DL; 16.67 ppb "average"). Copper has been detected at trace concentrations twice in both MW-7A (2 of 10 values ≥DL; 11.70 ppb average) and MW-9A (2 of 10 values ≥DL; 11.25 ppb average). As noted for arsenic above, copper was also detected once in MW-13 (1 of 9 values ≥DL; 17.44 ppb "average"). The spatial distribution of copper is quite similar to that described above for arsenic.

Nickel has been measured above the DL in only 7 out of 45 total analyses of samples of bedrock groundwater. Nickel was detected once in upgradient bedrock well MW-1A (1 of 10 values ≥DL; 19.70 ppb "average"). Nickel has been detected more often in MW-9A (4

of 10 values ≥DL; 41.60 ppb average) and MW-13 (2 of 9 values ≥DL; 23.78 ppb average). The spatial diagram for nickel suggests that Gold Run has some influence on its distribution. However, the typical absence of nickel in bedrock groundwater, as well as the low-to-trace "average" concentrations noted for the three monitor wells above, suggest that it is not a concern in bedrock groundwater.

By comparison, zinc has been measured above the DL in 20 out of 44 total analyses of bedrock groundwater (Appendix H). Zinc has commonly been detected in upgradient bedrock well MW-1A (5 of 10 values ≥DL; 40.80 ppb average), and in the only samples of record for upgradient wells MW-16A (1 of 1 values ≥DL; 21.00 ppb "average") and MW-17A (1 of 1 values ≥DL; 36.00 ppb average). These observations would suggest that there may be ugradient sources of zinc. However, zinc is also prevalent at low concentrations in the bedrock wells MW-7A (5 of 10 values ≥DL; 20.60 ppb average), MW-9A (2 of 9 values ≥DL; 40.56 ppb average) and MW-13 (3 of 9 values ≥DL; 14.28 ppb average). As previously mentioned, the common presence of elevated concentrations of zinc in the overburden monitor wells around the impoundments suggests that they are probable sources of zinc on site. The presence of zinc in the bedrock wells MW-7A and MW-9A, suggests that some infiltration of zinc-contaminated overburden groundwater (see Section 4.2.5.1) into bedrock has occurred.

The spatial contours of zinc in bedrock groundwater closely resemble those which describe the potentiometric surface of the bedrock groundwater (Figure 3-5, Figure 3-6; See Chapter 3). This observation suggests that (1) zinc is widely distributed as a dissolved constituent in local bedrock groundwater (2) Gold Run strongly influences the distribution of zinc in bedrock groundwater. The potential contribution of upgradient sources of zinc in bedrock groundwater should be further evaluated.

4.2.6.2 ***Selected Semivolatiles in Bedrock.*** Acenaphthene and naphthalene have not been detected above the DL in bedrock groundwater at IFG (45 of 45 total analyses ≤DL). Therefore, their spatial distribution maps are "artificial" and purely a function of 1/2 DL values in the database.

1,2,4-trichlorobenzene has been measured above the DL in 8 out of 45 total analyses of bedrock groundwater. 1,2,4-trichlorobenzene is most commonly detected in MW-9A (6 of 10 values ≥DL; 15.20 ppb average). The only other measured values of 1,2,4-trichlorobenzene above the DL were in MW-7A (2 of 10 values ≥DL; 7.90 ppb average).

1,4-dichlorobenzene has only been measured above the DL once out of 52 total analyses of bedrock groundwater. This isolated "hit" of 1,4-dichlorobenzene was observed in MW-7A (1 of 11 values ≥DL; 7.91 ppb "average"). Therefore, the spatial distribution map for this compound is "artificial," as it is largely a function of 1/2 DL values in the database.

Chlorobenzene has been measured at trace concentrations above the DL in only 6 out of 45 total analyses of bedrock groundwater. Two bedrock monitor wells, MW-7A (3 of 10 values ≥DL; 1.77 ppb average) and MW-9A (3 of 10 values ≥DL; 2.25 ppb average) account for all of the reported measurements of chlorobenzene above the DL. The spatial distribution map for this compound is also "artificial," as it is largely a function of 1/2 DL values in the database. In addition, the infrequent occurrence of trace levels of this compound in MW-7A and MW-9A suggest that it is not a concern in bedrock groundwater at IFG.

4.2.6.3 ***Selected VOCs in bedrock.*** Benzene has only been measured above the DL in 3 out of 44 total analyses of bedrock groundwater. MW-7A (2 of 10 values ≥DL; 3.85 ppb average) and MW-13 (1 of 8 values ≥DL; 1.54 ppb average) account for all three trace "hits" of benzene. Therefore, the spatial distribution map for this compound is also "artificial," as it is largely a function of 1/2 DL values in the database.

Methylene chloride has been measured above the DL in 12 out of 45 total analyses of bedrock groundwater. Methylene chloride has been occasionally detected at trace concentrations in upgradient monitor well MW-1A (4 of 10 values ≥DL; 1.52 ppb average). Trace concentrations of methylene chloride are infrequently reported in downgradient monitor wells MW-7A (2 of 10 values ≥DL; 1.25 ppb average) and MW-9A (2 of 10 values ≥DL; 1.45 ppb average).

Methylene chloride has also been detected twice at trace concentrations in upgradient well MW-14 (2 of 3 values ≥DL; 2.17 ppb average), and in the only samples of record for MW-16A (1 of 1 values ≥DL; 3.00 ppb "average") and MW-17A (1 of 1 values ≥DL; 1.00 ppb "average"). However, the "hits" of methylene chloride in upgradient wells MW-14, MW-16A and MW-17A measured in the October 1990 samples were reported by NAC to be both below the quantitative detection limit ("J") and present in the method blank ("B") (Appendix G). As methylene chloride is a common laboratory solvent, and has been found in method blanks the trace concentrations reported in bedrock groundwater at IFG are likely to be related to laboratory contamination.

1,1,1-TCA has been measured at trace concentrations above the DL in 10 out of 45 total analyses of bedrock groundwater. Two monitor wells, MW-9A (5 of 10 values ≥DL; 2.40 ppb average) and MW-13 (5 of 9 values ≥DL; 1.77 ppb average) account for all of the reported values of 1,1,1-TCA above the DL. The occasional trace "hits" of 1,1,1-TCA in these monitor wells are expected to be attributable to off-site sources. However, the extremely low reported concentrations of 1,1,1-TCA indicate that this compound is not a significant problem in bedrock groundwater beneath IFG.

As noted for the available VOC data and spatial maps for the overburden groundwater monitor wells at IFG, TCE and its degradation products, (1,2-trans-DCE and vinyl chloride), are the most prevalent VOCs observed in bedrock groundwater. TCE has been measured above the DL in 33 out of 45 total analyses of bedrock groundwater. Similarly, 1,2-trans-DCE has been measured above the DL in 34 out of 48 total analyses of bedrock groundwater. Vinyl chloride is less commonly measured above the DL in bedrock groundwater (8 out of 45 total analyses).

TCE has always been observed at concentrations above the DL in upgradient monitor well MW-1A (10 of 10 values ≥DL; 64.28 ppb average). TCE was also observed in the only sample of record for upgradient monitor well MW-16A (1 of 1 values ≥DL; 70 ppb "average"). Likewise, TCE was observed in the only sample of record for bedrock monitor well MW-15A east of Gold Run (1 of 1 values ≥DL; 120 ppb "average"). TCE has been consistently observed in all of the downgradient DGW bedrock monitor wells at IFG: e.g.

MW-7A (4 of 10 values ≥DL; 1.41 ppb average), MW-9A (9 of 10 values ≥DL; 105.77 ppb average) and MW-13 (8 of 9 values ≥DL; 208.47 ppb average).

The spatial contour map for TCE in bedrock groundwater is strikingly similar to the potentiometric surface maps of bedrock groundwater provided in Chapter 3 (Figure 3-5, Figure 3-6). This map supports the inference that a discharge zone of local groundwater is present along Gold Run in the vicinity of MW-13 (Chapter 3). The consistent presence of TCE in upgradient bedrock groundwater, (as well as the available information on the NAPC across Parkway Avenue from IFG), suggests that the NAPC is the source of TCE in local groundwater.

1,2-trans-DCE has consistently been observed at concentrations above the DL in upgradient monitor well MW-1A (9 of 10 values ≥DL; 53.21 ppb average). 1,2-trans-DCE was observed in the only sample of record from upgradient monitor well MW-16A (1 of 1 values ≥DL; 3 ppb "average"), as well as that from MW-15A (1 of 1 values ≥DL; 33 ppb "average") east of Gold Run. As noted for TCE above, 1,2-trans-DCE has been consistently observed in all of the downgradient bedrock monitor wells at IFG: e.g. MW-7A (5 of 10 values ≥DL; 2.85 ppb average), MW-9A (10 of 13 values ≥DL; 13.56 ppb average) and MW-13 (8 of 9 values ≥DL; 53.17 ppb average). The spatial map for 1,2-trans-DCE also supports the inference that a discharge zone of local groundwater is present along Gold Run in the vicinity of MW-13 (Chapter 3).

Historical records indicate no instances of the use of TCE at IFG. The NAPC facility upgradient of IFG has a documented history of releases of TCE and other contaminants. Therefore, the NAPC is the probable source of TCE and its principal anaerobic degradation products, (1,2-trans-DCE and vinyl chloride), observed in both the overburden and bedrock groundwater beneath IFG (Rowland and Eisenberg, 1989). The impact of the NAPC on the groundwater and surface water quality observed at IFG is discussed in detail in Chapter 5.

4.3 TEMPORAL VARIATION OF SELECTED PARAMETERS IN GROUNDWATER

Five of IFG's monitor wells were selected for analysis of the temporal variation of the target parameters described above: MW-1A (upgradient/bedrock), MW-4 (downgradient/ overburden), MW-5 (downgradient/overburden), MW-11 (downgradient/overburden) and MW-13 (downgradient/bedrock). As noted above for the selection of the "target" parameters, these monitor wells were selected to provide a representative "cross-section" of the groundwater issues on site. The temporal diagrams for these selected parameters and monitor wells are included in Appendix E2. The period of record from May 1988 to October 1990 was selected for preparation of these diagrams because of the relatively consistent availability and quality of the data for these wells/parameters during that time.

4.3.1 Analysis of Temporal Variation: Selected Metals

Arsenic was infrequently detected above the DL in the selected monitor wells as follows: MW-1A (2 of 10 values ≥DL; 2.58 ppb average, 1.00 ppb minimum, 5.00 ppb maximum), MW-4 (9 of 13 values ≥DL; 9.36 ppb average, 1.00 ppb minimum, 26.00 ppb maximum), MW-5 (5 of 13 values ≥DL; 5.60 ppb average, 1.00 ppb minimum, 15.00 ppb maximum), MW-11 (2 of 13 values ≥DL; 2.55 ppb average, 0.50 ppb minimum, 5.00 ppb maximum) and MW-13 (1 of 9 values ≥DL; 2.32 ppb average, 0.50 ppb minimum, 5.41 ppb maximum). As noted in the temporal diagram for arsenic, the predominance of ≤DL values (shown as = DL) for most wells causes their plots to be quite similar. The similarity of the trends of arsenic in MW-4 and MW-5 is noteworthy, especially with respect to their mutually reported maximums in August 1988.

The temporal plot and data summary for **copper** illustrate that most of the reported values for this metal were below the DL in the selected monitor wells, (with the exception of MW-11) (Appendix E2, Appendix H). MW-11 has shown consistent hits of copper (13 of 13 values ≥DL; 84.89 ppb average, 8.20 ppb minimum, 140.00 ppb maximum). The plot of copper concentrations in MW-11 suggests that seasonal lows occur in the late winter (February) and seasonal highs in late summer (August); however, copper concentrations in MW-11 show an increasing trend overall. MW-13 exhibited a single "spike" of 90 ppb copper

in November 1989 (1 of 9 values ≥DL; 17.44 ppb "average," 1.00 ppb minimum, 90.00 ppb maximum). This information, coupled with the interpretation of the spatial distribution of copper in overburden groundwater described above, suggests that the southern component of flow may be dominant in the overburden.

As noted for copper above, the temporal plot and data summary for **nickel** show that most of the reported values for this metal were below the DL in the selected monitor wells, (with the exception of monitor wells MW-4 and MW-5) (Appendix E2, Appendix H). Nickel is commonly measured above the DL in MW-4 (10 of 13 values ≥DL; 135.62 ppb average, 25.00 ppb minimum, 433.00 ppb maximum) and consistently in MW-5 (13 of 13 values ≥DL; 496.00 ppb average, 170.00 ppb minimum, 592.00 ppb maximum). Seasonal trends of nickel concentrations are apparent in MW-4 and MW-5, with relative "lows" observed in the fall (November) sampling events and the relative "highs" in the spring-summer (May-August) events (Appendix E2).

The selected monitor wells do not include those which appear to be the relative hot spots of **zinc**. As described above, the highest concentrations of zinc are observed in MW-2 (12 of 13 values ≥DL; 651.46 ppb average, 10.00 ppb minimum, 1600.00 ppb maximum), MW-3 (12 of 13 values ≥DL; 133.92 ppb average, 10.00 ppb minimum, 870.00 ppb maximum) and MW-7 (12 of 13 values ≥DL; 331.54 ppb average, 10.00 ppb minimum, 745.00 ppb maximum). Of the monitor wells selected for temporal analysis, zinc is most commonly observed in the upgradient bedrock well MW-1A (5 of 10 values ≥DL; 40.80 ppb average, 10.00 ppb minimum, 260.00 ppb maximum) and the downgradient overburden well MW-11 (9 of 13 values ≥DL; 55.93 ppb average, 2.35 ppb minimum, 297.00 ppb maximum).

The temporal plot for zinc does show an interesting feature for the selected wells: zinc is observed to increase simultaneously in these wells from ≤DL in November 1989 to a common spike in May 1990. Upgradient bedrock monitor well MW-1A exhibited the highest concentration of zinc of the selected wells in May 1990 (260 ppb). Although the former sludge impoundments are suspected to be an on-site source of zinc observed in the groundwater at IFG, the common presence of zinc in MW-1A, as well as its typical presence in upgradient well MW-14 (3 of 3 values ≥DL; 177.67 ppb average, 33.00 ppb minimum,

330.00 ppb maximum), suggests that upgradient sources of zinc may also exist. Furthermore, zinc was also measured above the DL in the only samples of record (October 1990) for upgradient monitor wells MW-17A (36 ppb) and MW-16A (21 ppb), as well as MW-15 (130 ppb) east of Gold Run (Appendix H; Table 4-1).

4.3.2 Analysis of Temporal Variation: Selected Semivolatiles

The temporal variation of **acenaphthene** in the selected monitor wells is unremarkable, as it has typically not reported to be present, (with the exception of MW-5). Acenaphthene is reported at trace concentrations in MW-5, e.g. below the quantitative detection limit (typically ≤20 ppb). Acenaphthene has been reported in MW-5 in 5 out of 13 total analyses (7.63 ppb average, 3.00 ppb minimum, 10.00 ppb maximum).

As noted above for acenaphthene, the temporal variation of **1,2,4-trichlorobenzene** is also unremarkable, as it has not been reported to be present in the selected monitor wells (Appendix H; Table 4-1).

The temporal plot and data summary for **naphthalene** illustrate that most of the reported values for this compound were below the DL in the selected monitor wells, (with the exception of MW-5) (Appendix E2, Appendix H). Naphthalene is commonly detected in MW-5 (11 of 13 values ≥DL; 29.94 ppb average, 10.00 ppb minimum, 53.50 ppb maximum). Naphthalene exhibits a seasonal trend in MW-5 which is similar to that described above for nickel, i.e. summer "highs" and winter "lows."

The temporal plot and data summary for **bis(2-ethylhexyl) phthalate** illustrate that almost all of the reported values for this compound were below the DL in the selected monitor wells (Appendix E2, Appendix H). The dominance of ≤DL values (shown as = DL) for most wells causes their plots for this compound to be quite similar. An isolated spike of 770 ppb of bis(2-ethylhexyl) phthalate occurred in MW-13 in February 1989. However, as previously mentioned, bis(2-ethylhexyl) phthalate is a very common field and laboratory contaminant, (i.e. from the handling of samples with latex gloves and plastic ware). Since this compound

has also been occasionally detected in method blanks, it is difficult to determine the extent to which this spike is attributable to site conditions.

The temporal plot and data summary for **1,4-dichlorobenzene** show that most of the reported values for this compound were below the DL in the selected monitor wells, (with the exception of MW-4) (Appendix E2, Appendix H). The temporal diagram for 1,4-dichlorobenzene shows that occasional hits of this compound have occurred in MW-4 (7 of 14 values ≥DL; 16.04 ppb average, 5.00 ppb minimum, 36.00 ppb maximum).

The temporal diagram for **chlorobenzene** is the most complicated of the selected semivolatile compounds. Chlorobenzene is commonly detected in MW-4 (8 of 13 values ≥DL; 10.67 ppb average, 1.00 ppb minimum, 29.10 ppb maximum) and consistently detected in MW-5 (13 of 13 values ≥DL; 32.86 ppb average, 15.70 ppb minimum, 60.00 ppb maximum). Some seasonal variation of chlorobenzene is apparent in the plot for MW-5, although it is not as clear as that observed for the other compounds described above. A single "spike" of 17.60 ppb of chlorobenzene was observed to occur in MW-11 in February 1989, the same sampling event for which the maximum value of chlorobenzene was observed in MW-5 (60.00 ppb).

4.3.3 Analysis of Temporal Variation: Selected VOCs

The temporal diagram for **benzene** is nearly identical to that described above for chlorobenzene. As noted for chlorobenzene, MW-5 shows the most consistent hits of benzene (12 of 13 values ≥DL; 12.67 ppb average, 1.00 ppb minimum, 24.00 ppb maximum). The temporal pattern of benzene in MW-5 is also quite similar to that observed for chlorobenzene in this well. Although the UST area is expected to be the principal source of benzene and other aromatic VOCs on site, these observations suggest that the sludge impoundments represent separate, secondary sources of benzene.

The temporal diagram for **methylene chloride** shows that from May 1988 through November 1989, most of the reported values for this compound were below the DL in the selected monitor wells. For the following two sampling events, February 1990 and May 1990, low levels of methylene chloride were measured in MW-1A, MW-4 and MW-5. The highest

observed concentration of methylene chloride was measured in the May 1990 sample from MW-5 (17 ppb). MW-5 has also had the highest average concentration of this compound (3 of 10 values ≥DL; 3.37 ppb average). The trace concentrations of methylene chloride typically reported in IFG's groundwater, (coupled with its frequent detection in the laboratory method blanks), suggest that this compound is not a concern at IFG.

The temporal diagram for **1,1,1-TCA** shows that most of the reported values for this compound were below the DL in the selected monitor wells, with the exception of MW-13 (5 of 9 values ≥DL; 1.77 ppb average, 1.00 ppb minimum, 3.80 ppb maximum). The trace levels of TCA that are occasionally observed in MW-13 and other downgradient monitor wells at IFG are suspected to be related to the former sludge impoundments.

The temporal diagram for TCE shows comparable trends for upgradient bedrock monitor well MW-1A (10 of 10 values ≥DL; 64.28 ppb average, 3.00 ppb minimum, 138.20 ppb maximum) and downgradient overburden monitor well MW-11 (10 of 13 values ≥DL; 21.91 ppb average, 1.00 ppb minimum, 45.00 ppb maximum). The plots for MW-1A and MW-11 suggest a coupled seasonal trend of TCE concentrations in these wells, with relative "highs" occurring in the late winter (February 1990) to summer (May 1989, August 1988) sampling events. The relative "lows" of TCE in MW-1A and MW-11 have consistently occurred in the fall sampling events of record, e.g. the November 1988, November 1989 and October 1990 sampling events. The trend of TCE concentrations in MW-13 (8 of 9 values ≥DL; 208.47 ppb average, 1.00 ppb minimum, 433.60 ppb maximum) is more erratic, and does not appear to correlate with those observed for MW-1A and MW-11. As previously discussed, TCE has not been observed above the DL in overburden monitor wells MW-4 and MW-5.

The temporal diagram for **1,2-trans-DCE** shows a strong seasonal trend in MW-1A (9 of 10 values ≥DL; 53.21 ppb average, 1.00 ppb minimum, 96.80 ppb maximum). As noted above for TCE, the "lows" of 1,2-trans-DCE have consistently occurred in the fall sampling events of record, e.g. the November 1988, November 1989 and October 1990 sampling events. The relative "highs" of 1,2-trans-DCE in MW-1A have typically occurred in the summer, e.g. August 1988 and 1989. A quarterly sampling event was not conducted in August 1990 in anticipation of this project; therefore the relative "high" of 1,2-trans-DCE in MW-1A was

observed in February 1990. As noted above for TCE, the trend of 1,2-trans-DCE in MW-13 (8 of 9 values ≥DL; 53.17 ppb average, 1.00 ppb minimum, 96.60 ppb maximum) is more erratic, and does not appear to correlate with that of MW-1A. However, the average and maximum values of 1,2-trans-DCE observed in MW-1A and MW-13 are nearly identical (Appendix H; Table 4-1). A seasonal trend of 1,2-trans-DCE is also apparent in MW-4, though it does not appear to be closely coupled to the trends of either MW-1A or MW-11.

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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw01	Bis(2-ethylhexyl) Phthalate	21.33	25.93	3	51	3	1	2
Mw01	Chemical Oxygen Demand, Dissolved	15.78	17.34	2.5	35.4	3	1	2
Mw01	Copper, Dissolved (as Cu)	8.33	5.2	2.5	12.5	3	2	1
Mw01	Depth to water from ground level	8.68	0	8.68	8.68	1	0	1
Mw01	Depth to water from top of casing	11	0	11	11	1	0	1
Mw01	Manganese, Dissolved	18.5	16.93	7.5	38	3	2	1
Mw01	Nickel	21.33	3.21	19	25	3	2	1
Mw01	Phenols, Total Recoverable	5.97	3.78	2.5	10	3	2	1
Mw01	Specific Conductance	488.33	207.73	360	728	3	0	3
Mw01	Total Dissolved Solids (TDS)	586.67	559.4	160	1220	3	0	3
Mw01	Zinc, Dissolved	327.67	155.65	150	440	3	0	3
Mw01	pH	6.7	0	6.7	6.7	1	0	1
Mw01a	1,1-Dichloroethane	1.62	0.8	1	2.7	10	9	1
Mw01a	1,2-trans-Dichloroethylene	53.21	33.51	1	96.8	10	1	9
Mw01a	Arsenic, Dissolved (as As)	2.58	2.05	1	5	10	8	2
Mw01a	Barium, Dissolved (as Ba)	598	427.83	100	1000	10	9	1
Mw01a	Bis(2-ethylhexyl) Phthalate	15.34	16.17	3	57.6	10	5	5
Mw01a	Chemical Oxygen Demand, Dissolved	16.28	19.06	0.5	57	10	5	5
Mw01a	Chloroform	1.6	0.77	1	2.5	10	9	1
Mw01a	Depth to water from ground level	9.71	0	9.71	9.71	1	0	1
Mw01a	Depth to water from top of casing	11.6	0	11.6	11.6	1	0	1
Mw01a	Lead, Dissolved (as Pb)	23.15	25.4	2.5	89	10	9	1
Mw01a	Manganese, Dissolved	4349	1659.9	260	5830	10	0	10
Mw01a	Methylene Chloride	1.52	0.99	1	4	10	6	4
Mw01a	Nickel	19.7	7.59	5	25	10	9	1
Mw01a	Phenols, Total Recoverable	18.15	28.85	2.5	100	10	8	2
Mw01a	Specific Conductance	525.1	122.07	205	635	10	0	10
Mw01a	Total Dissolved Solids (TDS)	298.7	43.54	230	366	10	0	10
Mw01a	Total Organic Carbon (TOC)	0.94	1.39	0.5	4.9	10	9	1
Mw01a	Total Organic Halogen (TOX)	14	34.67	0.5	110	10	8	2
Mw01a	Trichloroethylene	64.28	41.15	3	138.2	10	0	10
Mw01a	Vinyl Chloride	7.87	8.24	1	30.1	10	3	7
Mw01a	Zinc, Dissolved	40.8	77.68	10	260	10	5	5
Mw01a	pH	7.2	1.06	6.4	8.4	3	0	3
Mw02	1,1,1-Trichloroethane	1.37	0.6	1	2.5	13	12	1
Mw02	1,1-Dichloroethane	1.82	1.42	1	6	13	12	1
Mw02	1,2-trans-Dichloroethylene	8.68	4.41	1	17	13	1	12
Mw02	Arsenic, Dissolved (as As)	2.46	2.1	0.5	5	13	12	1
Mw02	Barium, Dissolved (as Ba)	477.85	437.86	34	1000	13	10	3
Mw02	Bis(2-ethylhexyl) Phthalate	10.95	7.28	2	29.2	13	9	4
Mw02	Cadmium, Dissolved (as Cd)	9.98	7.25	1.8	26	13	7	6
Mw02	Chemical Oxygen Demand, Dissolved	46.92	39.98	2.5	152	13	3	10
Mw02	Copper, Dissolved (as Cu)	8.57	4.09	1	12.5	13	11	2
Mw02	Cyanide, Total (as Cn)	1.82	4.04	0.01	10	11	10	1
Mw02	Depth to water from ground level	6.37	0	6.37	6.37	1	0	1
Mw02	Depth to water from top of casing	8.1	0	8.1	8.1	1	0	1
Mw02	Lead, Dissolved (as Pb)	23.19	20.43	2.5	78	13	11	2
Mw02	Manganese, Dissolved	954.62	875.16	56	2650	13	0	13
Mw02	Methylene Chloride	1.78	1.72	1	7.24	13	10	3
Mw02	Nickel	37.69	24.66	5	83	13	4	9
Mw02	Phenols, Total Recoverable	19.46	33.98	0.75	100	13	8	5
Mw02	Specific Conductance	1051.23	205.66	790	1420	13	0	13
Mw02	Total Dissolved Solids (TDS)	674.15	194.86	380	1080	13	0	13
Mw02	Total Organic Carbon (TOC)	1.54	3.74	0.5	14	13	12	1
Mw02	Total Organic Halogen (TOX)	43.04	117.94	0.5	414	13	11	2
Mw02	Trichloroethylene	5.43	5.97	0.95	21	13	5	8
Mw02	Zinc, Dissolved	651.46	551.24	10	1600	13	1	12
Mw02	pH	6.75	0.15	6.6	7	6	0	6

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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw03	1,1,1-Trichloroethane	1.36	0.59	1	2.5	13	10	3
Mw03	1,1-Dichloroethane	4.92	2.82	1	9.6	13	4	9
Mw03	1,2,4-Trichlorobenzene	8.46	3.08	0.95	12	13	9	4
Mw03	1,2-trans-Dichloroethylene	15.32	6.07	0.8	23.4	13	1	12
Mw03	1,4 Dichlorobenzene	7.18	3.56	1	10	14	13	1
Mw03	Arsenic, Dissolved (as As)	2.54	2.06	0.5	5	13	12	1
Mw03	Barium, Dissolved (as Ba)	511.23	443.96	23	1000	13	10	3
Mw03	Bis(2-ethylhexyl) Phthalate	28.72	61.49	2	230	13	9	4
Mw03	Cadmium, Dissolved (as Cd)	5.95	3.75	1.8	10	13	11	2
Mw03	Chemical Oxygen Demand, Dissolved	19.25	16.85	1	50.9	13	5	8
Mw03	Chlorobenzene	1.62	0.85	1	3	13	12	1
Mw03	Copper, Dissolved (as Cu)	11.76	12.05	1	50	13	10	3
Mw03	Depth to water from ground level	4.8	0	4.8	4.8	1	0	1
Mw03	Depth to water from top of casing	7.1	0	7.1	7.1	1	0	1
Mw03	Lead, Dissolved (as Pb)	21.58	18.22	2.5	76	13	10	3
Mw03	Manganese, Dissolved	1126.54	167.37	920	1600	13	0	13
Mw03	Mercury, Dissolved	0.57	0.39	0.1	1	13	12	1
Mw03	Methylene Chloride	1.47	0.95	1	4.19	13	10	3
Mw03	Nickel	35.62	24.5	5	83	13	7	6
Mw03	Phenols, Total Recoverable	30.94	56.34	0.75	194	13	8	5
Mw03	Specific Conductance	711.08	69.48	580	806	13	0	13
Mw03	Total Dissolved Solids (TDS)	484.38	145.17	310	872	13	0	13
Mw03	Total Organic Carbon (TOC)	1.07	2.05	0.5	7.9	13	12	1
Mw03	Total Organic Halogen (TOX)	89.19	272.91	0.5	984	13	11	2
Mw03	Trichloroethylene	17.83	5.63	0.95	24	13	1	12
Mw03	Vinyl Chloride	2.23	1.92	1	5	13	12	1
Mw03	Zinc, Dissolved	133.92	224.22	10	870	13	1	12
Mw03	pH	6.45	0.18	6.2	6.7	6	0	6
Mw04	1,1-Dichloroethane	3.49	2.02	1	7.8	13	6	7
Mw04	1,2-Dichloroethane	2.7	5.45	1	20.8	13	12	1
Mw04	1,2-trans-Dichloroethylene	3.14	2.38	0.8	6.8	13	6	7
Mw04	1,3 Dichlorobenzene	7.83	2.63	4	10	14	11	3
Mw04	1,4 Dichlorobenzene	16.04	9.12	5	36	14	7	7
Mw04	4-Bromophenyl Ether	10	0	10	10	1	0	1
Mw04	Arsenic, Dissolved (as As)	9.36	7.48	1	26	13	4	9
Mw04	Barium, Dissolved (as Ba)	535.54	395.18	100	1000	13	9	4
Mw04	Benzene	1.42	0.55	1	2.2	13	10	3
Mw04	Bis(2-ethylhexyl) Phthalate	16.72	22.44	2	86.4	13	8	5
Mw04	Cadmium, Dissolved (as Cd)	6.08	4.33	1.8	13	13	12	1
Mw04	Chemical Oxygen Demand, Dissolved	116	188.86	2.5	739	13	1	12
Mw04	Chlorobenzene	10.67	9.17	1	29.1	13	5	8
Mw04	Copper, Dissolved (as Cu)	7.99	4.2	1	12.5	13	12	1
Mw04	Depth to water from ground level	7.61	0	7.61	7.61	1	0	1
Mw04	Depth to water from top of casing	9.51	0	9.51	9.51	1	0	1
Mw04	Di-n-butyl Phthlate	10.91	8.08	5	36.8	13	12	1
Mw04	Ethylbenzene	2.18	1.96	1	7	12	10	2
Mw04	Lead, Dissolved (as Pb)	17.38	9.38	2.5	30	13	12	1
Mw04	Manganese, Dissolved	3370	682.08	1450	4400	13	0	13
Mw04	Mercury, Dissolved	6.65	22.04	0.1	80	13	12	1
Mw04	Methylene Chloride	1.45	0.72	1	3	13	12	1
Mw04	Naphthalene	7.12	3.94	0.8	10	13	11	2
Mw04	Nickel	135.62	135.65	25	433	13	3	10
Mw04	Phenols, Total Recoverable	17.38	27.29	0.75	100	13	7	6
Mw04	Specific Conductance	1103.62	133.29	830	1426	13	0	13
Mw04	Total Dichlorobenzenes	8.6	12.98	1	36	12	8	4
Mw04	Total Dissolved Solids (TDS)	659.23	59.24	540	770	13	0	13
Mw04	Total Organic Carbon (TOC)	2.15	5.96	0.5	22	13	12	1
Mw04	Total Organic Halogen (TOX)	21.35	55.46	0.5	190	13	11	2
Mw04	Vinyl Chloride	7.35	5.65	1	16	13	6	7
Mw04	Zinc, Dissolved	24.5	28.79	2.35	100	13	7	6
Mw04	pH	6.65	0.16	6.5	6.8	6	0	6

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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw05	1,3 Dichlorobenzene	7.38	3.34	0.95	10	14	13	1
Mw05	1,4 Dichlorobenzene	9.78	3.27	5	16.8	14	10	4
Mw05	2,4-Dimethylphenol	7.37	3.62	1.4	10	13	12	1
Mw05	Acenaphthene	7.63	3.13	3	10	13	8	5
Mw05	Arsenic, Dissolved (as As)	5.6	4.48	1	15	13	8	5
Mw05	Barium, Dissolved (as Ba)	764.23	392.76	100	1100	13	9	4
Mw05	Benzene	12.67	5.46	1	24	13	1	12
Mw05	Bis(2-ethylhexyl) Phthalate	11.85	11.22	4	44.2	13	10	3
Mw05	Cadmium, Dissolved (as Cd)	6.24	4.63	1.8	15	13	12	1
Mw05	Chemical Oxygen Demand, Dissolved	74.42	28.87	2.5	130	13	1	12
Mw05	Chlorobenzene	32.86	12.03	15.7	60	13	0	13
Mw05	Chromium, Dissolved, Hexavalent (as	10.77	4.83	5	25	13	12	1
Mw05	Copper, Dissolved (as Cu)	8.61	3.25	4.2	12.5	13	10	3
Mw05	Depth to water from ground level	7.81	0	7.81	7.81	1	0	1
Mw05	Depth to water from top of casing	9.71	0	9.71	9.71	1	0	1
Mw05	Di-n-butyl Phthlate	9.63	3.84	5	20.2	13	12	1
Mw05	Ethylbenzene	32.99	26	1	83	13	3	10
Mw05	Fluorene	7.17	3.79	0.95	10	13	9	4
Mw05	Lead, Dissolved (as Pb)	23.12	15.3	2.5	50	13	10	3
Mw05	Manganese, Dissolved	1002.38	191.37	690	1480	13	0	13
Mw05	Methylene Chloride	3.37	5.43	1	17	13	10	3
Mw05	Naphthalene	29.94	12.61	10	53.5	13	2	11
Mw05	Nickel	496	223.76	170	959	13	0	13
Mw05	Phenanthrene	7.14	3.87	1	10	13	9	4
Mw05	Phenols, Total Recoverable	18.69	25.82	0.75	100	13	6	7
Mw05	Specific Conductance	1043.38	169.15	620	1185	13	0	13
Mw05	Tetrachloroethylene	1.42	0.67	1	2.8	13	12	1
Mw05	Toluene	1.62	0.85	1	3	13	12	1
Mw05	Total Dichlorobenzenes	3.28	3.79	1	11.3	12	10	2
Mw05	Total Dissolved Solids (TDS)	602.77	58.7	480	710	13	0	13
Mw05	Total Organic Carbon (TOC)	2.54	7.35	0.5	27	13	12	1
Mw05	Total Organic Halogen (TOX)	8	27.04	0.5	98	13	12	1
Mw05	Zinc, Dissolved	35.69	30.2	10	110	13	4	9
Mw05	pH	6.52	0.13	6.3	6.7	6	0	6
Mw06	1,2-Dichloroethane	2.29	2.89	1	10.9	13	11	2
Mw06	1,3 Dichlorobenzene	7.64	3.51	0.95	10	14	13	1
Mw06	1,4 Dichlorobenzene	8.18	2.41	4	10	14	12	2
Mw06	Arsenic, Dissolved (as As)	4.2	3.29	1	11	13	10	3
Mw06	Barium, Dissolved (as Ba)	560.31	337.42	100	1000	13	7	6
Mw06	Benzene	18.05	9.7	1	38	13	1	12
Mw06	Bis(2-ethylhexyl) Phthalate	11.88	11.94	3	45.6	13	9	4
Mw06	Cadmium, Dissolved (as Cd)	6.49	4.49	1.8	15	13	11	2
Mw06	Chemical Oxygen Demand, Dissolved	214.73	69.42	2.5	281	13	1	12
Mw06	Chlorobenzene	71.18	23.73	1	99	13	1	12
Mw06	Copper, Dissolved (as Cu)	7.99	4.2	1	12.5	13	12	1
Mw06	Cyanide, Total (as Cn)	1.55	3.75	0.01	10	13	12	1
Mw06	Depth to water from ground level	7.72	0	7.72	7.72	1	0	1
Mw06	Depth to water from top of casing	10.1	0	10.1	10.1	1	0	1
Mw06	Di-n-butyl Phthlate	13.62	17.68	5	72	13	12	1
Mw06	Lead, Dissolved (as Pb)	27.65	23.6	2.5	74	13	9	4
Mw06	Manganese, Dissolved	1618.46	247.62	1250	1990	13	0	13
Mw06	Methylene Chloride	1.52	0.92	1	4	13	12	1
Mw06	Naphthalene	7.12	4.01	0.8	10	13	12	1
Mw06	Nickel	32.38	22.61	5	87	13	7	6
Mw06	Phenols, Total Recoverable	21.83	28.59	0.75	100	13	7	6
Mw06	Specific Conductance	1673.46	464.88	182	1985	13	0	13
Mw06	Tetrachloroethylene	1.42	0.67	1	2.8	13	12	1
Mw06	Toluene	1.62	0.85	1	3	13	12	1
Mw06	Total Dichlorobenzenes	3.23	2.34	1	6.1	12	8	4
Mw06	Total Dissolved Solids (TDS)	1037	307.83	121	1450	13	0	13
Mw06	Total Organic Carbon (TOC)	6.31	20.94	0.5	76	13	12	1
Mw06	Total Organic Halogen (TOX)	36.62	130.22	0.5	470	13	12	1
Mw06	Zinc, Dissolved	40.15	58.24	2.35	210	13	6	7
Mw06	pH	6.57	0.12	6.4	6.7	6	0	6

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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw07	1,4 Dichlorobenzene	7.25	3.43	2	10	14	13	1
Mw07	2,4-Dimethylphenol	7.57	3.31	1.4	10	13	11	2
Mw07	Acenaphthene	6.92	4.1	1	10	13	8	5
Mw07	Arsenic, Dissolved (as As)	3.63	2.26	1	8	13	9	4
Mw07	Barium, Dissolved (as Ba)	6723.08	5483.46	100	14800	13	4	9
Mw07	Benzene	17.58	8.67	1	30.7	13	2	11
Mw07	Bis(2-ethylhexyl) Phthalate	12.2	8.46	4	30.8	13	8	5
Mw07	Cadmium, Dissolved (as Cd)	6.24	4.63	1.8	15	13	12	1
Mw07	Chemical Oxygen Demand, Dissolved	196.65	72.28	2.5	330	13	1	12
Mw07	Chlorobenzene	69.08	15.52	34.7	88	13	0	13
Mw07	Copper, Dissolved (as Cu)	10.22	3.98	4.2	18	13	10	3
Mw07	Depth to water from ground level	10.43	0	10.43	10.43	1	0	1
Mw07	Depth to water from top of casing	12.82	0	12.82	12.82	1	0	1
Mw07	Di-n-butyl Phthlate	10.45	6.49	5	30.8	13	12	1
Mw07	Diethyl Phthalate	7.54	3.43	1	10	13	11	2
Mw07	Ethylbenzene	50.8	23.32	3.6	71.9	13	2	11
Mw07	Fluorene	7.32	3.62	1	10	13	9	4
Mw07	Lead, Dissolved (as Pb)	25.69	22.95	2.5	83	13	9	4
Mw07	Manganese, Dissolved	299.23	404.53	88	1290	13	0	13
Mw07	Mercury, Dissolved	0.61	0.48	0.1	1.4	13	12	1
Mw07	Methylene Chloride	1.68	1.39	1	5.99	13	10	3
Mw07	Naphthalene	53.82	27.87	10	96.5	13	2	11
Mw07	Nickel	490.85	46.1	430	592	13	0	13
Mw07	Phenanthrene	7.19	3.79	1	10	13	11	2
Mw07	Phenols, Total Recoverable	25.71	28.45	0.75	100	13	7	6
Mw07	Specific Conductance	2097.08	404.07	1646	2970	13	0	13
Mw07	Toluene	1.82	1.15	1	4.7	13	9	4
Mw07	Total Dissolved Solids (TDS)	1206.15	152.95	1000	1510	13	0	13
Mw07	Total Organic Carbon (TOC)	5.85	19.28	0.5	70	13	12	1
Mw07	Total Organic Halogen (TOX)	17.38	60.88	0.5	220	13	12	1
Mw07	Zinc, Dissolved	331.54	243.93	10	745	13	1	12
Mw07	pH	6.7	0.18	6.4	6.9	6	0	6
Mw07a	1,1-Dichloroethane	1.22	0.47	1	2.2	10	6	4
Mw07a	1,2,4-Trichlorobenzene	7.9	3.48	2	10	10	8	2
Mw07a	1,2-trans-Dichloroethylene	2.85	2.25	1	6.6	10	5	5
Mw07a	1,3 Dichlorobenzene	7.82	3.22	1	10	11	10	1
Mw07a	1,4 Dichlorobenzene	7.91	3.02	2	10	11	10	1
Mw07a	Arsenic, Dissolved (as As)	2.55	1.92	1	5	10	8	2
Mw07a	Barium, Dissolved (as Ba)	599	427.02	100	1000	10	9	1
Mw07a	Benzene	3.85	5.21	1	16.9	10	8	2
Mw07a	Bis(2-ethylhexyl) Phthalate	13.16	9.29	4	32.6	10	4	6
Mw07a	Cadmium, Dissolved (as Cd)	14.1	23.8	2.5	81	10	9	1
Mw07a	Chemical Oxygen Demand, Dissolved	22.55	18.85	2.5	69	10	2	8
Mw07a	Chlorobenzene	1.77	0.84	1	2.9	10	7	3
Mw07a	Copper, Dissolved (as Cu)	11.7	8.85	1	35	10	8	2
Mw07a	Depth to water from ground level	13.2	0	13.2	13.2	1	0	1
Mw07a	Depth to water from top of casing	15.25	0	15.25	15.25	1	0	1
Mw07a	Di-n-butyl Phthlate	12.57	13.94	5	58.4	13	12	1
Mw07a	Diethyl Phthalate	10.78	8.09	5	32.8	10	9	1
Mw07a	Lead, Dissolved (as Pb)	75.6	185.2	2.5	602	10	8	2
Mw07a	Manganese, Dissolved	1123	558.21	100	1800	10	0	10
Mw07a	Methylene Chloride	1.25	0.54	1	2.5	10	8	2
Mw07a	Phenols, Total Recoverable	17.3	29.3	2.5	100	10	6	4
Mw07a	Specific Conductance	470.3	35.18	410	511	10	0	10
Mw07a	Total Dichlorobenzenes	2.01	1.73	1	5	9	8	1
Mw07a	Total Dissolved Solids (TDS)	278.5	38.83	207	360	10	0	10
Mw07a	Total Organic Carbon (TOC)	1.22	2.28	0.5	7.7	10	9	1
Mw07a	Total Organic Halogen (TOX)	14.45	44.11	0.5	140	10	9	1
Mw07a	Trichloroethylene	1.41	0.71	1	3	10	6	4
Mw07a	Zinc, Dissolved	20.6	16.97	8	58	10	5	5
Mw07a	pH	6.5	0.1	6.4	6.6	3	0	3

Statistical Summary of Compounds Detected In Groundwater MWs
Inland Fisher Guide (IFG) Trenton NJ Groundwater Impact Study

Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw08	Arsenic, Dissolved (as As)	22	0	22	22	1	0	1
Mw08	Barium, Dissolved (as Ba)	41	0	41	41	1	0	1
Mw08	Chemical Oxygen Demand, Dissolved	22.75	28.64	2.5	43	2	1	1
Mw08	Chromium, Dissolved (as Cr)	57	0	57	57	1	0	1
Mw08	Copper, Dissolved (as Cu)	70	0	70	70	1	0	1
Mw08	Cyanide, Total (as Cn)	0.17	0	0.17	0.17	1	0	1
Mw08	Depth to water from ground level	10.95	0	10.95	10.95	1	0	1
Mw08	Depth to water from top of casing	12.75	0	12.75	12.75	1	0	1
Mw08	Lead, Dissolved (as Pb)	22	0	22	22	1	0	1
Mw08	Manganese, Dissolved	180	0	180	180	1	0	1
Mw08	Nickel	86	0	86	86	1	0	1
Mw08	Specific Conductance	794	159.99	668	974	3	0	3
Mw08	Total Dissolved Solids (TDS)	1790	0	1790	1790	1	0	1
Mw08	Zinc, Dissolved	55	0	55	55	1	0	1
Mw08	pH	7.1	0.2	6.9	7.3	3	0	3
Mw09a	1,1,1-Trichloroethane	2.4	1.56	1	4.8	10	5	5
Mw09a	1,1-Dichloroethane	2.92	1.78	1	5.9	10	2	8
Mw09a	1,2,4-Trichlorobenzene	15.2	7.5	6	25.2	10	4	6
Mw09a	1,2-Dichloropropane	3.79	8.31	1	27.4	10	9	1
Mw09a	1,2-trans-Dichloroethylene	13.56	9.57	0.8	29.2	13	3	10
Mw09a	Arsenic, Dissolved (as As)	2.81	2	1	5.08	10	8	2
Mw09a	Bis(2-ethylhexyl) Phthalate	18.2	38.71	2	146.6	13	9	4
Mw09a	Cadmium, Dissolved (as Cd)	6.9	3.8	2.5	10	10	9	1
Mw09a	Chemical Oxygen Demand, Dissolved	15.16	16.79	0.5	50.7	10	6	4
Mw09a	Chlorobenzene	2.25	0.96	1	3.5	10	7	3
Mw09a	Chloroform	2.65	1.45	0.8	5.1	10	4	6
Mw09a	Copper, Dissolved (as Cu)	11.25	2.91	7	18	10	8	2
Mw09a	Depth to water from ground level	15.88	0	15.88	15.88	1	0	1
Mw09a	Depth to water from top of casing	18.2	0	18.2	18.2	1	0	1
Mw09a	Di-n-butyl Phthlate	9.63	3.84	5	20.2	13	12	1
Mw09a	Lead, Dissolved (as Pb)	25.18	30.12	2.5	106	10	8	2
Mw09a	Manganese, Dissolved	912.9	1328.47	10	3760	10	1	9
Mw09a	Methylene Chloride	1.45	0.76	1	3	10	8	2
Mw09a	Nickel	41.6	35.72	20	138	10	6	4
Mw09a	Phenols, Total Recoverable	19.45	28.74	2.5	100	10	8	2
Mw09a	Specific Conductance	844.8	110.55	590	978	10	0	10
Mw09a	Total Dichlorobenzenes	2.22	1.7	1	5	9	7	2
Mw09a	Total Dissolved Solids (TDS)	498.8	49.05	420	572	10	0	10
Mw09a	Total Organic Carbon (TOC)	4.49	2.32	0.5	6.7	10	2	8
Mw09a	Total Organic Halogen (TOX)	179.74	169.48	0.5	476	10	2	8
Mw09a	Trichloroethylene	105.77	96.3	1	322.2	10	1	9
Mw09a	Vinyl Chloride	1.9	1.66	1	5	10	9	1
Mw09a	Zinc, Dissolved	40.56	68.75	2.5	200	9	7	2
Mw09a	pH	6.57	0.25	6.3	6.8	3	0	3

Statistical Summary of Compounds Detected in Groundwater MWs
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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw10	1,1,1-Trichloroethane	2.49	2.88	1	10.1	13	10	3
Mw10	1,2,4-Trichlorobenzene	7.3	3.74	0.95	10	13	12	1
Mw10	1,2-trans-Dichloroethylene	3.83	2.58	1	8.8	13	4	9
Mw10	Arsenic, Dissolved (as As)	2.76	1.75	1	5	12	8	4
Mw10	Barium, Dissolved (as Ba)	509.75	435.6	100	1000	12	9	3
Mw10	Bis(2-ethylhexyl) Phthalate	15.77	20.09	5	78	13	9	4
Mw10	Cadmium, Dissolved (as Cd)	6.13	4.05	1.8	10	12	11	1
Mw10	Chemical Oxygen Demand, Dissolved	9.33	7.34	0.5	24.6	12	5	7
Mw10	Chloroform	1.28	0.62	0.8	2.5	13	12	1
Mw10	Copper, Dissolved (as Cu)	8.83	3.52	1	12.5	12	9	3
Mw10	Depth to water from ground level	13.4	0	13.4	13.4	1	0	1
Mw10	Depth to water from top of casing	15.5	0	15.5	15.5	1	0	1
Mw10	Lead, Dissolved (as Pb)	16.79	8.23	5	25	12	10	2
Mw10	Manganese, Dissolved	128.17	222.87	7.5	684	12	5	7
Mw10	Methylene Chloride	1.71	1.21	1	5	13	11	2
Mw10	Nickel	18.83	7.53	5	25	12	9	3
Mw10	Phenols, Total Recoverable	9.42	5.93	0.75	19	12	9	3
Mw10	Specific Conductance	473.27	202.76	0	702	11	1	10
Mw10	Total Dissolved Solids (TDS)	254.59	137.62	0.5	404	11	2	9
Mw10	Total Organic Carbon (TOC)	3.67	3.45	0.5	12	12	5	7
Mw10	Total Organic Halogen (TOX)	182.37	455.81	0.5	1600	12	5	7
Mw10	Trichloroethylene	8.45	5.88	1	16.4	13	3	10
Mw10	Zinc, Dissolved	65.53	107.27	10	390	12	3	9
Mw10	pH	6.68	0.45	6.1	7.2	4	0	4
Mw11	1,1-Dichloroethane	1.91	1.32	1	5.6	13	12	1
Mw11	1,2-trans-Dichloroethylene	9.58	5.81	1	21.9	13	2	11
Mw11	Arsenic, Dissolved (as As)	2.55	2.03	0.5	5	13	11	2
Mw11	Barium, Dissolved (as Ba)	483.08	429.17	100	1000	13	11	2
Mw11	Bis(2-ethylhexyl) Phthalate	22.37	42.39	5	160	13	10	3
Mw11	Cadmium, Dissolved (as Cd)	5.47	3.81	1.8	10	13	12	1
Mw11	Chemical Oxygen Demand, Dissolved	12.13	10.38	0.5	29.4	13	6	7
Mw11	Chlorobenzene	2.93	4.49	1	17.6	13	12	1
Mw11	Chloroform	1.2	0.58	0.8	2.5	13	12	1
Mw11	Copper, Dissolved (as Cu)	84.89	36.25	8.2	140	13	0	13
Mw11	Depth to water from ground level	14.03	0	14.03	14.03	1	0	1
Mw11	Depth to water from top of casing	16.08	0	16.08	16.08	1	0	1
Mw11	Lead, Dissolved (as Pb)	20.82	12.95	2.5	55	13	10	3
Mw11	Manganese, Dissolved	102.12	178.94	7.5	637	13	5	8
Mw11	Methylene Chloride	1.48	1.14	1	5	13	11	2
Mw11	Nickel	24.41	13.06	5	56	13	8	5
Mw11	Phenols, Total Recoverable	14.08	26.24	0.75	100	13	11	2
Mw11	Specific Conductance	385.62	75.11	240	479	13	0	13
Mw11	Total Dichlorobenzenes	3.85	7.51	1	27.2	12	11	1
Mw11	Total Dissolved Solids (TDS)	243	43.49	177	332	13	0	13
Mw11	Total Organic Carbon (TOC)	5.25	3.5	0.5	15	13	2	11
Mw11	Total Organic Halogen (TOX)	170.36	322.05	0.5	1200	13	2	11
Mw11	Trichloroethylene	21.91	14.72	1	45	13	3	10
Mw11	Vinyl Chloride	4.4	6.55	1	25.2	13	12	1
Mw11	Zinc, Dissolved	55.93	79.04	2.35	297	13	4	9
Mw11	pH	6.75	0.29	6.4	7.2	6	0	6

Statistical Summary of Compounds Detected In Groundwater MWs
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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw12	1,2-trans-Dichloroethylene	3.49	4.31	0.8	15.8	13	7	6
Mw12	Arsenic, Dissolved (as As)	2.94	2.05	0.5	5	13	11	2
Mw12	Barium, Dissolved (as Ba)	537.08	424.79	73	1000	13	9	4
Mw12	Bis(2-ethylhexyl) Phthalate	74.25	215.84	5	790	13	9	4
Mw12	Cadmium, Dissolved (as Cd)	5.85	4	1.8	10	13	12	1
Mw12	Chemical Oxygen Demand, Dissolved	11.58	8.04	1	25	13	5	8
Mw12	Chromium, Dissolved (as Cr)	10.62	8.56	5	38	13	12	1
Mw12	Chromium, Dissolved, Hexavalent (as	13.54	14.44	5	61	13	12	1
Mw12	Copper, Dissolved (as Cu)	10.65	6.33	4.2	26	13	8	5
Mw12	Depth to water from ground level	14.4	0	14.4	14.4	1	0	1
Mw12	Depth to water from top of casing	16.7	0	16.7	16.7	1	0	1
Mw12	Di-n-butyl Phthlate	10.94	8.18	5	37.2	13	12	1
Mw12	Lead, Dissolved (as Pb)	19.84	15.88	2.5	64	13	11	2
Mw12	Manganese, Dissolved	22.88	24.8	7.5	96	13	7	6
Mw12	Methylene Chloride	1.63	1.03	1	4.31	13	12	1
Mw12	Nickel	27.69	14.38	5	50	13	8	5
Mw12	Specific Conductance	351.62	145.94	168	640	13	0	13
Mw12	Total Dissolved Solids (TDS)	239.38	79.22	157	403	13	0	13
Mw12	Total Organic Carbon (TOC)	3.22	1.5	0.5	5.98	13	2	11
Mw12	Total Organic Halogen (TOX)	188.82	355.1	0.5	1000	13	3	10
Mw12	Trichloroethylene	7.75	13.08	0.95	38.4	13	6	7
Mw12	Zinc, Dissolved	246.85	135.74	10	520	13	1	12
Mw12	pH	6.15	0.19	6	6.5	6	0	6
Mw13	1,1,1-Trichloroethane	1.77	1.2	1	3.8	9	4	5
Mw13	1,1-Dichloroethylene	1.28	0.83	1	3.5	9	7	2
Mw13	1,2-trans-Dichloroethylene	53.17	33.8	1	96.6	9	1	8
Mw13	Arsenic, Dissolved (as As)	2.32	2.12	0.5	5.41	9	8	1
Mw13	Barium, Dissolved (as Ba)	655.56	411.89	100	1000	9	8	1
Mw13	Benzene	1.54	0.74	1	2.5	8	7	1
Mw13	Bis(2-ethylhexyl) Phthalate	97.87	252.2	10	770	9	6	3
Mw13	Cadmium, Dissolved (as Cd)	8.5	5.36	2.5	19	9	8	1
Mw13	Chemical Oxygen Demand, Dissolved	8.67	7.89	2.5	25	9	5	4
Mw13	Copper, Dissolved (as Cu)	17.44	27.56	1	90	9	8	1
Mw13	Depth to water from ground level	3.96	0	3.96	3.96	1	0	1
Mw13	Depth to water from top of casing	6.1	0	6.1	6.1	1	0	1
Mw13	Di-n-octyl Phthalate	1	0	1	1	1	0	1
Mw13	Lead, Dissolved (as Pb)	17.44	9.24	2.5	25	9	8	1
Mw13	Manganese, Dissolved	148.56	105.14	65	388	9	0	9
Mw13	Mercury, Dissolved	0.71	0.37	0.1	1	9	8	1
Mw13	Nickel	23.78	7.08	11	38	9	7	2
Mw13	Phenols, Total Recoverable	11.33	6.68	2.5	22	9	6	3
Mw13	Specific Conductance	470.78	57.55	330	520	9	0	9
Mw13	Tetrachloroethylene	1	0	1	1	9	8	1
Mw13	Total Dissolved Solids (TDS)	301.78	55.36	170	358	9	0	9
Mw13	Total Organic Carbon (TOC)	1.09	0.82	0.5	2.63	9	5	4
Mw13	Total Organic Halogen (TOX)	118.88	140.11	0.5	400	8	2	6
Mw13	Trichloroethylene	208.47	135.67	1	433.6	9	1	8
Mw13	Zinc, Dissolved	14.28	11.71	2.5	39	9	6	3
Mw13	pH	7.1	0.26	6.8	7.3	3	0	3

Statistical Summary of Compounds Detected in Groundwater MWs
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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw14	Barium, Dissolved (as Ba)	200	87.18	100	260	3	1	2
Mw14	Bis(2-ethylhexyl) Phthalate	27	31.43	5	63	3	1	2
Mw14	Chemical Oxygen Demand, Dissolved	30.67	48.79	2.5	87	3	2	1
Mw14	Copper, Dissolved (as Cu)	16.67	7.22	12.5	25	3	2	1
Mw14	Depth to water from ground level	3.68	0	3.68	3.68	1	0	1
Mw14	Depth to water from top of casing	3.68	0	3.68	3.68	1	0	1
Mw14	Lead, Dissolved (as Pb)	5.33	4.91	2.5	11	3	2	1
Mw14	Manganese, Dissolved	135.83	126.3	7.5	260	3	1	2
Mw14	Mercury, Dissolved	0.41	0.38	0.1	0.84	3	1	2
Mw14	Methylene Chloride	2.17	0.29	2	2.5	3	1	2
Mw14	Specific Conductance	291	27.62	260	313	3	0	3
Mw14	Total Dissolved Solids (TDS)	223.33	25.17	200	250	3	0	3
Mw14	Total Organic Carbon (TOC)	2.07	2.71	0.5	5.2	3	2	1
Mw14	Total Organic Halogen (TOX)	15.67	26.27	0.5	46	3	2	1
Mw14	Zinc, Dissolved	177.67	148.65	33	330	3	0	3
Mw14	pH	7.7	0	7.7	7.7	1	0	1
Mw15	1,2-trans-Dichloroethylene	30	0	30	30	1	0	1
Mw15	Bis(2-ethylhexyl) Phthalate	1900	0	1900	1900	1	0	1
Mw15	Copper, Dissolved (as Cu)	37	0	37	37	1	0	1
Mw15	Depth to water from ground level	2.85	0	2.85	2.85	1	0	1
Mw15	Depth to water from top of casing	4.6	0	4.6	4.6	1	0	1
Mw15	Manganese, Dissolved	17	0	17	17	1	0	1
Mw15	Nickel	15	0	15	15	1	0	1
Mw15	Specific Conductance	140	0	140	140	1	0	1
Mw15	Tetrachloroethylene	4	0	4	4	1	0	1
Mw15	Total Dissolved Solids (TDS)	120	0	120	120	1	0	1
Mw15	Total Organic Carbon (TOC)	1.3	0	1.3	1.3	1	0	1
Mw15	Total Organic Halogen (TOX)	120	0	120	120	1	0	1
Mw15	Trichloroethylene	110	0	110	110	1	0	1
Mw15	Zinc, Dissolved	130	0	130	130	1	0	1
Mw15	pH	6.3	0	6.3	6.3	1	0	1
Mw15a	1,2-trans-Dichloroethylene	33	0	33	33	1	0	1
Mw15a	1,4 Dichlorobenzene	7.5	3.54	5	10	2	1	1
Mw15a	Bis(2-ethylhexyl) Phthalate	54	0	54	54	1	0	1
Mw15a	Depth to water from ground level	2.3	0	2.3	2.3	1	0	1
Mw15a	Depth to water from top of casing	5.8	0	5.8	5.8	1	0	1
Mw15a	Manganese, Dissolved	76	0	76	76	1	0	1
Mw15a	Specific Conductance	182	0	182	182	1	0	1
Mw15a	Tetrachloroethylene	4	0	4	4	1	0	1
Mw15a	Total Dissolved Solids (TDS)	120	0	120	120	1	0	1
Mw15a	Total Organic Carbon (TOC)	4.1	0	4.1	4.1	1	0	1
Mw15a	Total Organic Halogen (TOX)	190	0	190	190	1	0	1
Mw15a	Trichloroethylene	120	0	120	120	1	0	1
Mw15a	pH	5.7	0	5.7	5.7	1	0	1

Statistical Summary of Compounds Detected In Groundwater MWs
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Well	Parameter	Mean	Std. Dev.	Min.	Max.	# Total Analyses	# BDLs	# Detects
Mw16a	1,2-trans-Dichloroethylene	3	0	3	3	1	0	1
Mw16a	Barium, Dissolved (as Ba)	300	0	300	300	1	0	1
Mw16a	Chemical Oxygen Demand, Dissolved	63	0	63	63	1	0	1
Mw16a	Depth to water from ground level	7.91	0	7.91	7.91	1	0	1
Mw16a	Depth to water from top of casing	11.9	0	11.9	11.9	1	0	1
Mw16a	Manganese, Dissolved	5400	0	5400	5400	1	0	1
Mw16a	Methylene Chloride	3	0	3	3	1	0	1
Mw16a	Specific Conductance	220	0	220	220	1	0	1
Mw16a	Total Dissolved Solids (TDS)	250	0	250	250	1	0	1
Mw16a	Total Organic Carbon (TOC)	4.8	0	4.8	4.8	1	0	1
Mw16a	Total Organic Halogen (TOX)	75	0	75	75	1	0	1
Mw16a	Trichloroethylene	70	0	70	70	1	0	1
Mw16a	Zinc, Dissolved	21	0	21	21	1	0	1
Mw16a	pH	6.3	0	6.3	6.3	1	0	1
Mw17a	Barium, Dissolved (as Ba)	380	0	380	380	1	0	1
Mw17a	Depth to water from ground level	2.98	0	2.98	2.98	1	0	1
Mw17a	Depth to water from top of casing	2.98	0	2.98	2.98	1	0	1
Mw17a	Manganese, Dissolved	57	0	57	57	1	0	1
Mw17a	Methylene Chloride	1	0	1	1	1	0	1
Mw17a	Specific Conductance	210	0	210	210	1	0	1
Mw17a	Total Dissolved Solids (TDS)	210	0	210	210	1	0	1
Mw17a	Total Organic Carbon (TOC)	1.3	0	1.3	1.3	1	0	1
Mw17a	Total Organic Halogen (TOX)	59	0	59	59	1	0	1
Mw17a	Zinc, Dissolved	36	0	36	36	1	0	1
Mw17a	pH	6.6	0	6.6	6.6	1	0	1

CHAPTER 5

PRELIMINARY ASSESSMENT OF UPGRADIENT SOURCES OF GROUNDWATER AND SURFACE WATER CONTAMINATION

As part of this investigation, LMS reviewed the available information on the Naval Air Propulsion Center (NAPC) upgradient of IFG. NAPC has a history of environmental releases of VOCs, petroleum hydrocarbons, and metals. The nature and impact of these releases on the surface water and groundwater quality downgradient of the NAPC are discussed below.

IFG personnel met with representatives of NAPC on 31 March 1991. NAPC and IFG agreed to share certain types of information concerning their respective groundwater investigations at this meeting. NAPC officials informed IFG that several overburden monitor wells have been installed at their facility. Groundwater samples obtained from these overburden wells have shown concentrations of TCE that range from 50-500 ppb.

Subsequent to the 31 March 1991 meeting, IFG obtained a copy of the Initial Assessment Study (IAS) report from NAPC. This report provided information on the environmental conditions at NAPC based on a limited investigation conducted by BCM, its consultant. NAPC informed IFG that a remedial investigation/feasibility study (RI/FS) of their facility is currently in progress. The final report on the RI/FS being prepared by IT Corporation is expected within the next few months.

5.1 REVIEW OF INITIAL ASSESSMENT STUDY OF NAVAL AIR PROPULSION CENTER

LMS' review of the IAS revealed that all surface water drainage from the "industrialized" portion of the NAPC site is ultimately discharged via storm sewers to Gold Run, a tributary of the Delaware River. The downstream location where Gold Run enters IFG's property from a culvert beneath Parkway Avenue is estimated to be 0.25 mile away from NAPC, although the actual distance may be shorter. Groundwater flow is also to the south and east, towards Gold Run and IFG.

5.1.1 Summary of NAPC Waste Management to IFG Units

The IAS report provided by the NJDEP pursuant to IFG's Freedom of Information Act request described the waste management units in place at NAPC. These units are summarized in the following sections.

5.1.1.1 ***Brine Handling Area.*** The Brine Handling Area (Site No. 1 as ranked by the Navy Confirmation Study Ranking System [CSRS]) was the source area for trichloroethylene (TCE) surface runoff from 1955 to 1980 via the West End Drainage Ditch. The West End Drainage Ditch was an open swale until 1970, when it was replaced with a corrugated metal pipe. This ditch discharges to the West Trenton storm sewer system, which locally discharges to Gold Run.

The Brine Handling Area contains cooling towers, in which TCE is used as a heat-exchange medium. This system has an operating fluid volume of 25,000 gal. The TCE/brine cooling towers and related piping have been servicing the blower wing/brine system, the test wing, the exhauster wing, and related shops since 1955. BCM, NAPC's consultant, estimated that 500 gal have leaked from the system to the ground surface since 1955. This estimated release is a calculated percentage of the total amount of TCE (50,000 gal) known to have been replaced to the system since 1955. BCM attributes the difference between the total volume of TCE replaced by NAPC (50,000 gal) and that estimated to have leaked to the ground surface (500 gal or 1% of the total volume) to evaporation. Schwille (1988) points out that this type of estimate tends to be overly optimistic.

In addition to the releases of TCE from NAPC, three reported spills of TCE have occurred from the TCE/brine cooling system between 1978 and 1982. NAPC estimates the total combined volume of these spills to be 1200 gal.

Large quantities of ethylene glycol are apparently used in the brine cooling system as well. BCM estimates that 10,000 gal of ethylene glycol have leaked from the system since 1955. It is possible that ethylene glycol is used in a separate portion of the cooling system (e.g., as a "noncontact" coolant); however, the IAS report is not clear on this issue.

In 1985 a water sample taken from the head of the West End Drainage Ditch reportedly contained the following concentrations of TCE and its degradation products:

TCE	0.830 ppm
1,2-t-DCE	1.50 ppm
Vinyl chloride	0.110 ppm

5.1.1.2 ***Sludge Disposal Area.*** The Sludge Disposal Area is identified as Site No. 3 in the IAS. The IAS recommends that additional fieldwork be conducted to characterize this site. This area is pertinent because TCE could be present in the sludge, which was pumped from the industrial wastewater treatment plant (IWTP) intermittently for an unspecified five-year period between 1958 and 1979. The influent to the IWTP comes from deck drains throughout the facility, including the Brine Handling Area. The IAS states that prior to 1957 all of these drains discharged to the West End Drainage Ditch.

A soil sample taken by EPA in 1981 from a location immediately northwest of the sludge disposal area showed metals concentrations as follows:

METAL	CONCENTRATION (mg/kg)
Chromium	22.5-387.5
Lead	22.5-312.5
Mercury	0.001-0.24
Cadmium	1-17.5
Arsenic	2.5-6.75

5.1.1.3 ***Oil Contamination Near Building 34.*** The IAS speculates that Site No. 6, Oil Contamination Near Building 34, could be the result of leakage from the underground storage tanks (USTs) located nearby. NAPC began using these tanks for industrial wastewater sludge storage in 1957. If these USTs are leaking, they could represent an additional point source of subsurface TCE contamination, as the sludge stored in these USTs is known to contain chemicals from all site activities and locations, including the Brine Handling Area.

5.1.1.4 ***Barometric Well.*** NAPC constructed a barometric well in 1957 to catch all industrial discharges from on-site activities. Process wastewaters are pumped from this well to the

IWTP. This well is located in the middle of the site and is 50 ft deep and 13 ft in diameter. Since the water table at the site is present at between 4 and 9 ft BGS, the majority of this well is below the water table. It would be of interest to IFG to determine whether this well is in hydraulic connection with the site's groundwater.

5.2 DOWNGRADIENT MIGRATION OF TCE AND ASSOCIATED COMPOUNDS

Figures 5-1 and 5-2 are average computer-drawn spatial plots of average TCE and 1,2-Trans DCE in overburden groundwater beneath IFG. The time period from which the average was computed was August 1987 to October 1990. The data used is that generated from analyses performed on groundwater samples retrieved quarterly from overburden wells at IFG, in compliance with the provisions for their NJPDES/DGW permit.

The data set used for these plots is comprehensive for the southern half of the IFG property, but is not comprehensive for the northern portion. This fact is a result of the absence of overburden monitoring wells in the northern section of the property. This logistical consideration notwithstanding, some conclusions can be drawn from the information presented on these maps.

The presence of two discrete flow paths, as reflected in the measured concentrations of TCE and DCE, is indicated by these plots, existing beneath the southern portion of the property. The concentration that is centered around monitoring wells MW-10, -11, and -12 delineates the vicinity of. The average concentrations shown for the wells to the west and east, MW-8 and MW-7, respectively, clearly delineate decreases in average concentrations to the west and east of the "hot spot" around MW-10, -11, and -12.

The lower values to the east persist in that direction for the average reported concentrations at MW-6, -5, and -4. At MW-4 the average concentrations again begin to rise in an eastward direction reaching the highest values for both compounds at MW-15, on the east bank of Gold Run.

FIGURE 5-1

IFG-Trenton Groundwater Impact Study

Average Trichloroethylene Concentration in Overburden Monitor Wells August 1987 - October 1990

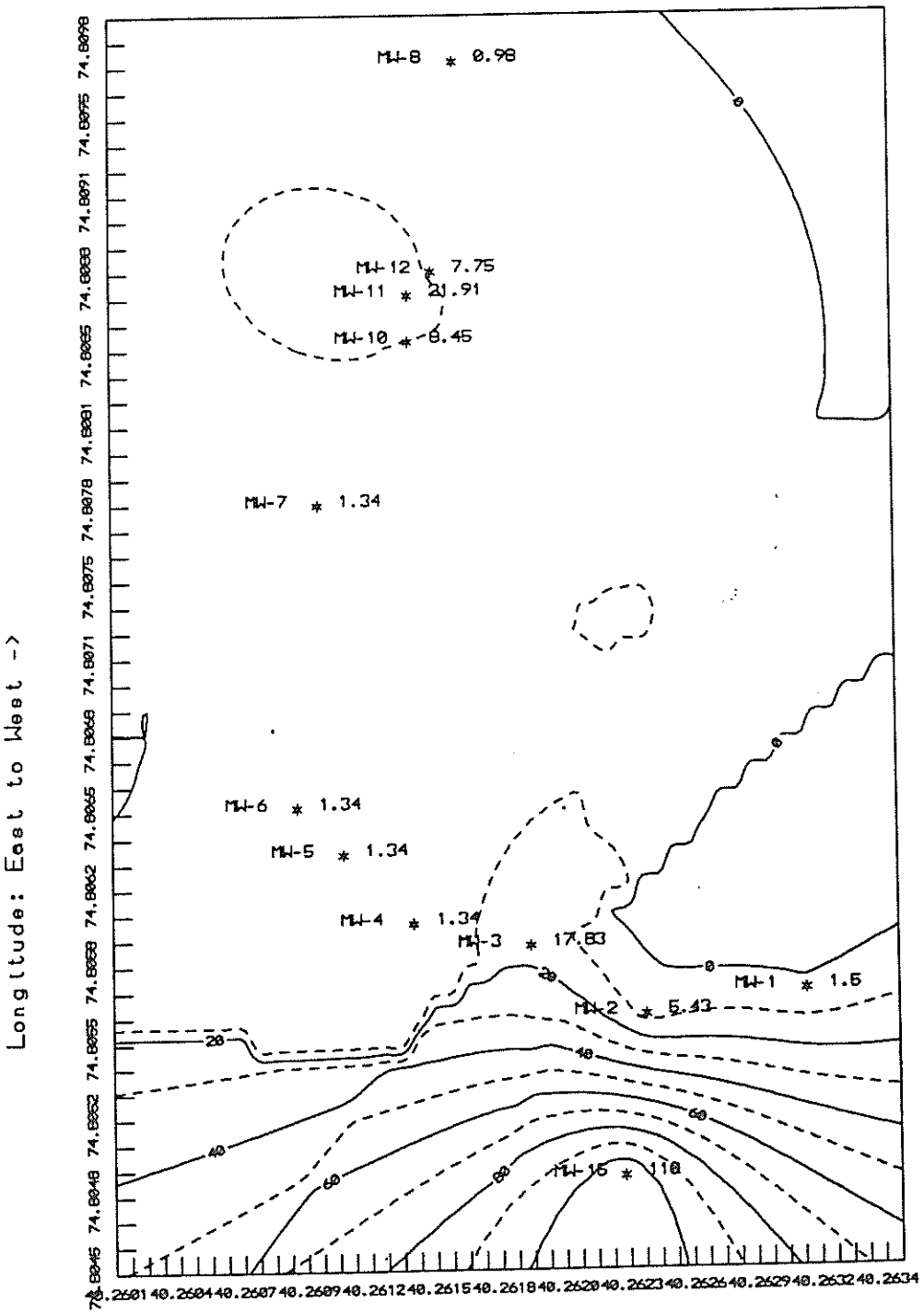
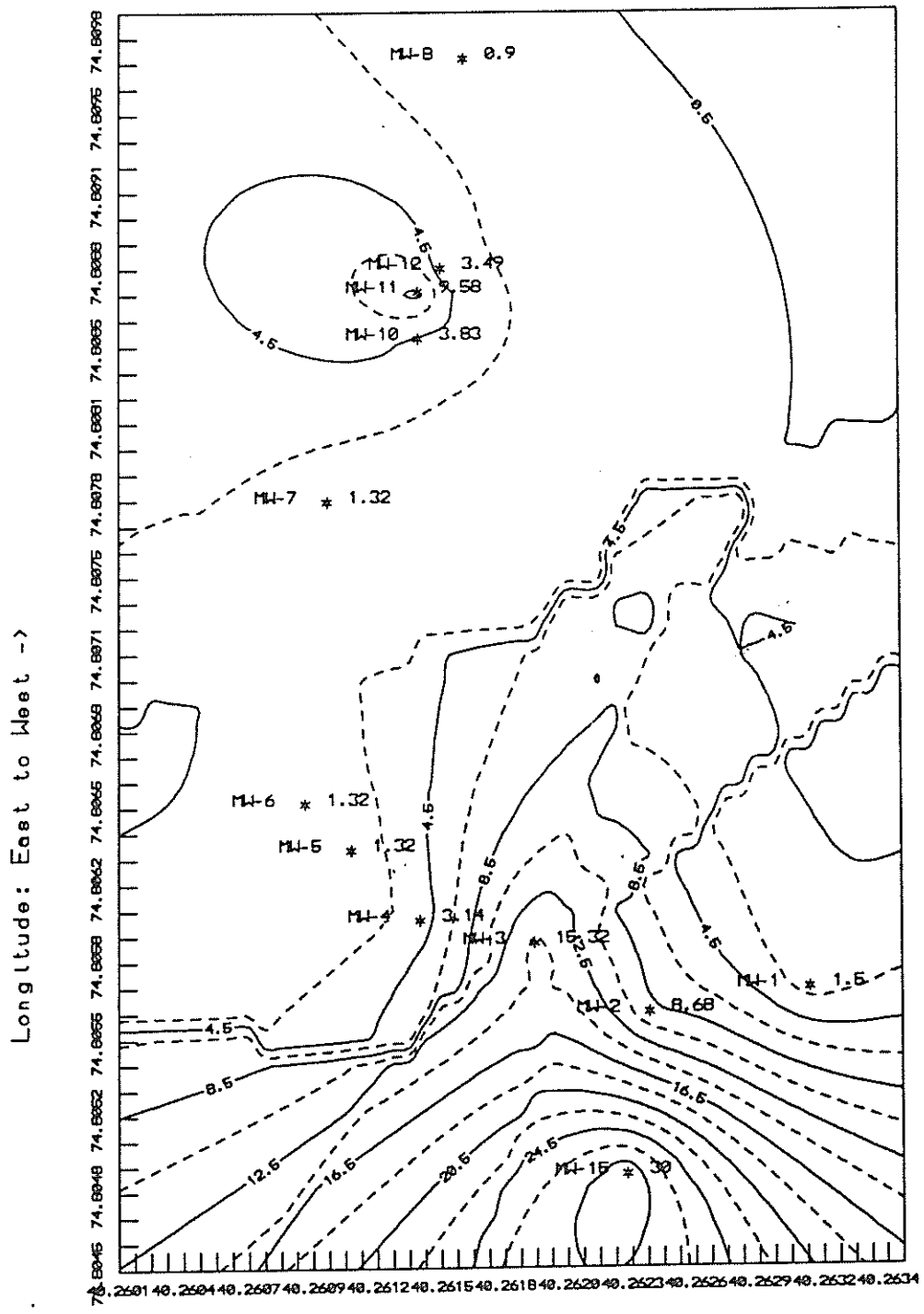


FIGURE 5-2

IFG-Trenton Groundwater Impact Study

Average 1,2-Trans-Dichloroethylene Concentration in Overburden Monitor Wells August 1987 - October 1990



This trend is consistent with the hydrogeological system delineated for the site. The presence of another discrete flow path for overburden groundwater is indicated in the vicinity of Gold Run, basically paralleling the stream at a lower elevation. Additionally, however, the interaction of Gold Run with overburden and also bedrock groundwater must be considered here.

Continuous water level measurements for a one month period (see Section 3.3)has shown that overburden groundwater at MW-15 is under greater head than the water in Gold Run, and therefore manifests a westward flow component. A southward component to flow is implicit in that the general topographic trend in the area is a decrease in elevation southward. This overburden flow direction east of Gold Run rules out the possibility of extensive eastward migration of TCE or DCE through shallow overburden groundwater to MW-15, where the highest concentrations are found. Also, extensive migration from Gold Run to MW-15 seems unlikely for the same reason. It is possible that during storm events this movement could occur.

Inspection of Figures 5-3 and 5-4, however, provides insight into the mechanism for the transport of the compounds of interest (TCE and DCE) into MW-15. These are spatial plots of the average concentrations for the two compounds as reported for the same time period cited above for the overburden wells. These plots show the spatial concentrations in the bedrock wells on site. The data sets for these plots are more comprehensive than for the former overburden plots. Consequently, the plots are much more useful in characterizing the compounds beneath the entire site.

A clear trend of increasing concentrations from northwest to southeast is indicated. Once again, two concentration trends are apparent beneath the site, coinciding closely with those displayed in the overburden spatial plots for the two compounds. One area of emphasized contaminant concentration occurs near MW-9A, which is located directly north of MW-10, -11, and -12, the site of the overburden groundwater "hot spot." East of MW-9A concentrations drop off dramatically and begin increasing again east of the midpoint between MW-7A and Gold Run. The second zone of TCE and DCE concentrations coincides closely with the one observed on the overburden plots - roughly parallel with Gold Run.

FIGURE 5-3

IFG-Trenton Groundwater Impact Study

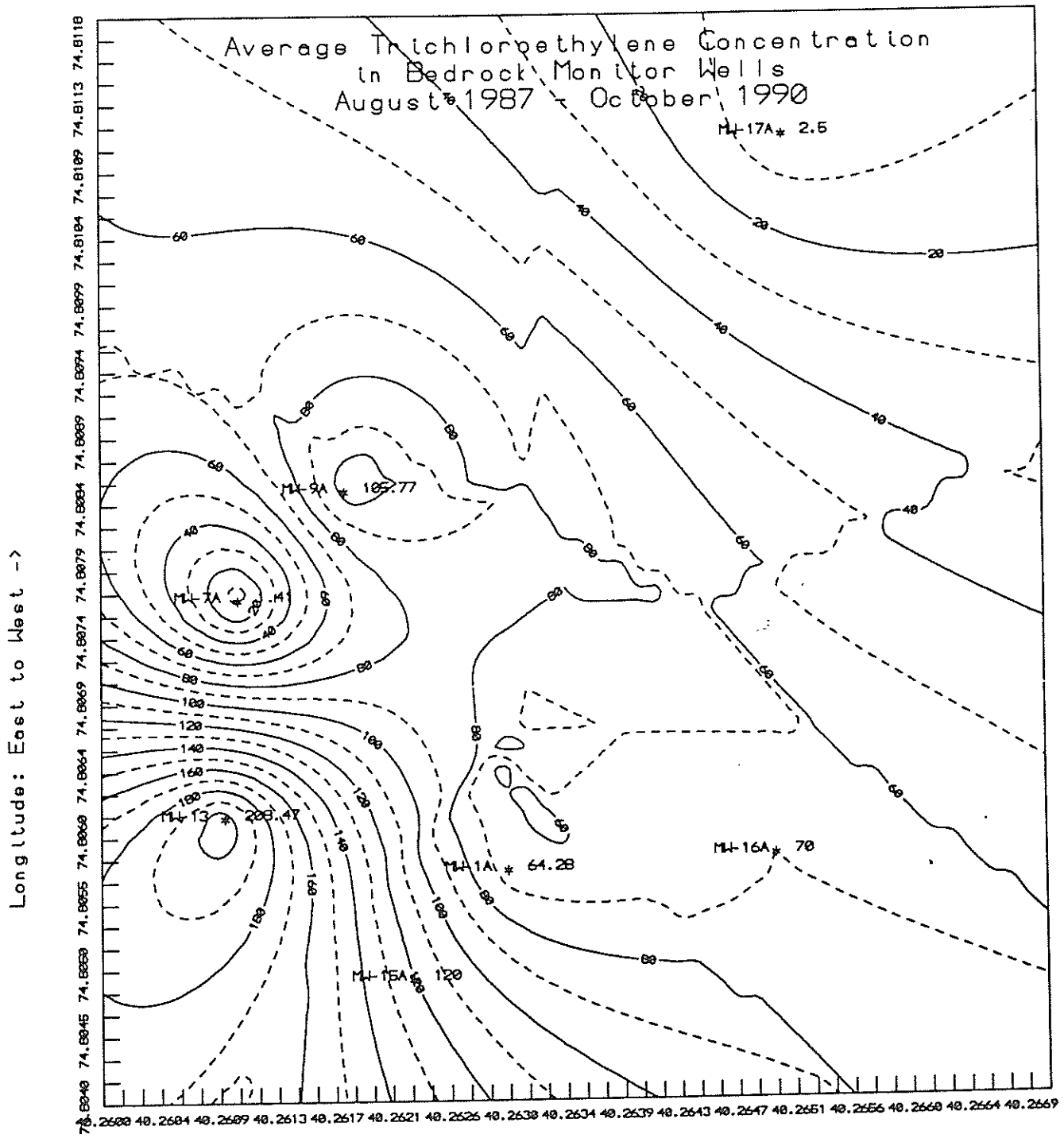
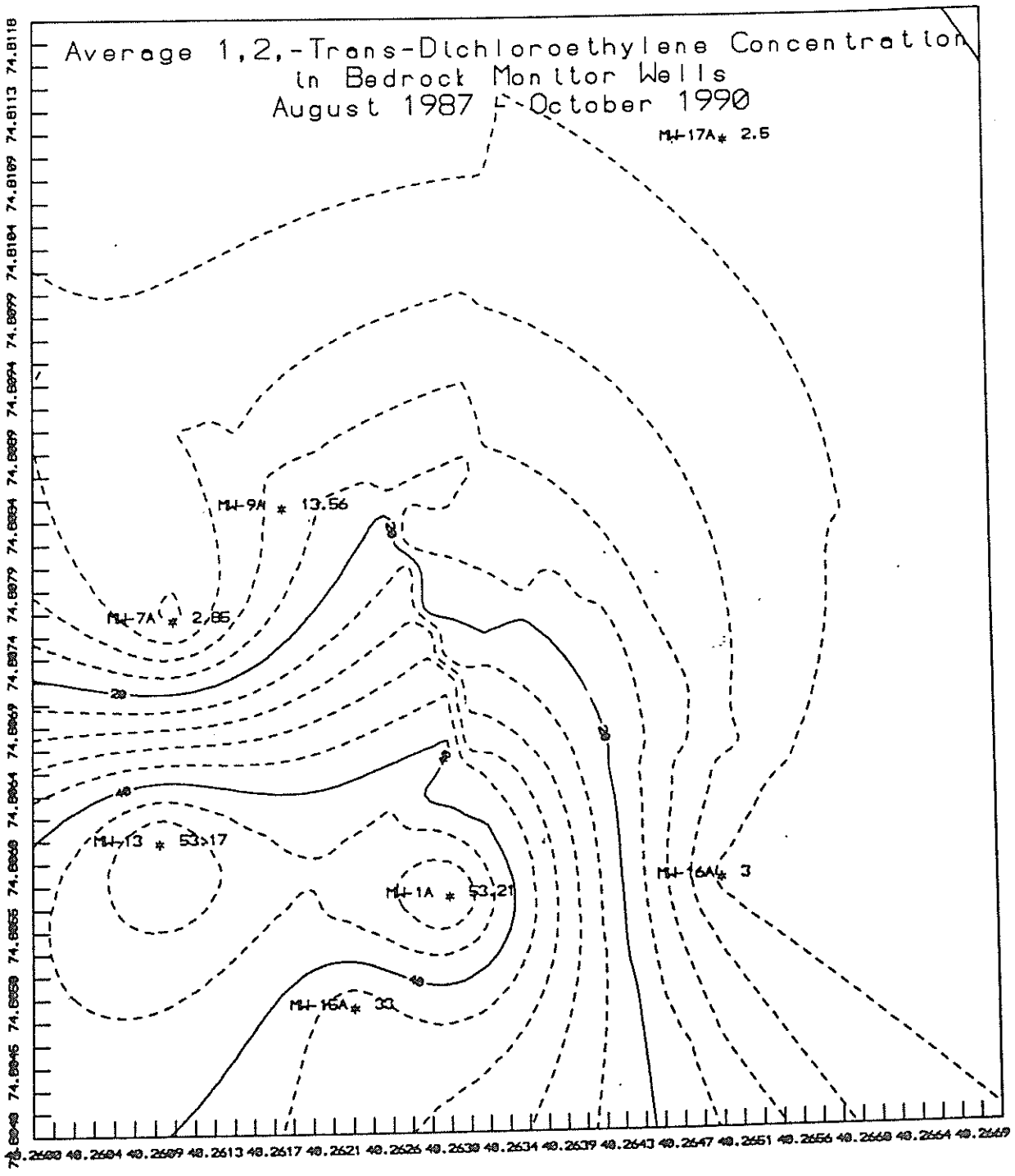


FIGURE 5-4

IFG-Trenton Groundwater Impact Study



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The values at MW-15 (overburden) and MW-15A (bedrock) for both chemicals are observed to be similar. Inasmuch as the overburden well, MW-15, is installed directly upon bedrock, and MW-15A is found to possess 16 ft of piezometric head, it is not surprising that the concentrations are very close because the upward component at MW-15A is found to be providing a pathway for these contaminants through the bedrock to the overburden aquifers (i.e., MW-15).

The presence of TCE and its associated degradation products in the groundwater beneath IFG suggests that these compounds have migrated at least this far downgradient from their source. Information pertinent to the understanding of the migration and fate of TCE released to groundwater is provided below.

5.2.1 Characteristics, Migration, and Fate of TCE

Trichloroethylene (TCE) is a relatively dense, immiscible, insoluble industrial solvent. TCE has a specific gravity of 1.47 and a maximum (ideal) solubility of 0.01 parts per hundred (100 ppm). TCE tends to exist as either a dense nonaqueous-phase liquid (DNAPL) or in the vapor phase in porous and fractured geologic media.

5.2.1.1 *Subsurface Fate and Migration.* Model experiments of TCE conducted by Schwille (1988) illustrate the tendency of TCE to exist in either the DNAPL or vapor phase in the subsurface. Schwille's (1988) experiments demonstrate that the advective and dispersive transport mechanisms of DNAPL and vapor-phase TCE in the subsurface are dominant relative to that of aqueous-phase TCE. The behavior of TCE as a sinking DNAPL contaminant in groundwater is also well documented (Schwille 1985; Connor 1989).

Surface spills or shallow subsurface discharges of TCE typically migrate downward until they reach a physical barrier to their movement or until the functional density of the groundwaters through which they migrate is equal to that of TCE. A common mode of TCE migration is to "coat" a pathway along a bedrock surface gradient and to continue to migrate along this route, pooling as DNAPL in bedrock depressions and sinking through fractures along the way. Common collection areas for DNAPL TCE include horizontal fine-grained strata (and the

overburden sediments, on flat locations or depressions of the bedrock surface, and horizontal bedding planes and fractures in competent rock. Subsurface features which are positioned in such a way that they possess a slight upward slope in the downgradient groundwater flow direction are expected to be the primary collection points of DNAPL TCE. Field data collected by LMS scientists attribute IFG groundwater pollutants from this source to pockets of DNAPL and vapor-phase TCE trapped in these subsurface features at the NAPC facilities. These represent continuing or episode sources for the release of aqueous-phase TCE over time. Such DNAPL and vapor-phase sources of TCE apparently are present in either the vadose zone, saturated overburden, or bedrock, or a combination of the three, upgradient of IFG.

The characteristics of TCE discussed above could greatly complicate any future remedial efforts undertaken at IFG. Since TCE has been found in groundwater beneath IFG and studies have documented the dominance of DNAPL TCE transport over aqueous - phase TCE transport it is probable that there is DNAPL TCE in the subsurface at locations not yet described but somewhere upgradient of the IFG facility. Consequently, TCE and its degradation products are likely to persist for an indefinite period of time in the groundwater (Figures 3-1 through 3-6). The migration and fate of TCE from upgradient sources could be greatly complicated by the following subsurface characteristics:

- The geometry of the bedrock surface in the area is expected to be complex, and is poorly understood to date. Substantial deformation of the Stockton Formation in the form of folds, faults, fractures, and joints is suspected and reported by others. The configuration of the competent bedrock surface is expected to exhibit a controlling influence on TCE fate and migration.

- The dip of the weathered bedrock surface (southeast) and the dip of the bedding planes (northwest) are in direct opposition. Therefore, the potential migration pathways of DNAPL TCE could be very complicated. TCE may "cascade" along the bedrock surface into fractures, creating isolated pockets of DNAPL.

Any "pump and treat" remedial activities that may be required of at IFG, would have negative consequences making it unable to avoid treating TCE and its degradation products. The installation and pumping of a network of groundwater interceptor wells at IFG would likely pull more of these compounds on site. This point is substantiated by the following fact: IFG

pumped ≈ 65,000 gal/day of contaminated groundwater into their WT facility (under the guidance of NJDEP) during the dewatering activities associated with the construction of their new oil/water separator system from late November 1990 through February 1991 (Appendix I). TCE was measured at a concentration of 2500 ppb in a groundwater sample obtained from upgradient bedrock well MW-1A on 28 January 1991 (Appendix I). TCE was measured at a concentration of 3900 ppb in a groundwater sample obtained from upgradient bedrock well MW-1A on 26 February 1991 (Appendix I). By comparison, these recently observed concentrations of TCE in MW-1A are *three orders of magnitude greater* than that measured prior to IFG's dewatering activities (estimated at 3 ppb in a sample obtained by LMS on 29 October 1990), and ≈ 18 times greater than the previously reported maximum concentration of TCE for this well (138.2 ppb; Table 4-1).

The mechanism at work here functions is response hydraulic head. The decrease in head pressure above and in the bedrock aquifer caused by the removal of overburden groundwater allows for increased migration from off-site through the leaky confined bedrock aquifer to the region beneath the site. As a result off-site TCE migrates to beneath the site. This scenario can be aggravated seasonally. Groundwater reserves typically undergo significant recharge during the winter. As shown in the continuous water levels plots shown in Appendix F. During the summer, when groundwater levels are typically depressed, the pressure differential between overburden and bedrock would likely not have been as pronounced.

So, even with the careful design and implementation of reinjection wells in a hypothetical future pump and treat system at IFG, the complicated fate and migration of TCE discussed above may make the further migration onsite of off-site contaminants unavoidable. Great care should be taken during the planning and conceptual design of IFG's future remedial activities to minimize these potential complications.

5.2.1.2 ***Surface Water Transport of TCE.*** The IAS recognizes that the surface water drainage from the industrialized portions of the NAPC facility ultimately discharges to Gold Run. The surface water and sediment contained in the drainage ditch near the NAPC's Brine Handling Area were found to exhibit concentrations of TCE, 1,2-DCE, and vinyl chloride (see above). The IAS report clearly demonstrates that the migration of TCE and its degradation products

via surface water runoff is a significant pathway for the downgradient transport of these contaminants.

Upstream surface water samples obtained from Gold Run by IFG have historically shown measurable concentrations of TCE, 1,2-DCE, vinyl chloride, and other organic compounds (Table 5-1). These compounds are generally quite volatile (especially vinyl chloride); and their detection in the upstream water samples suggests that they are undergoing relatively rapid transport.

5.2.2 Site-Specific Biodegradation of TCE

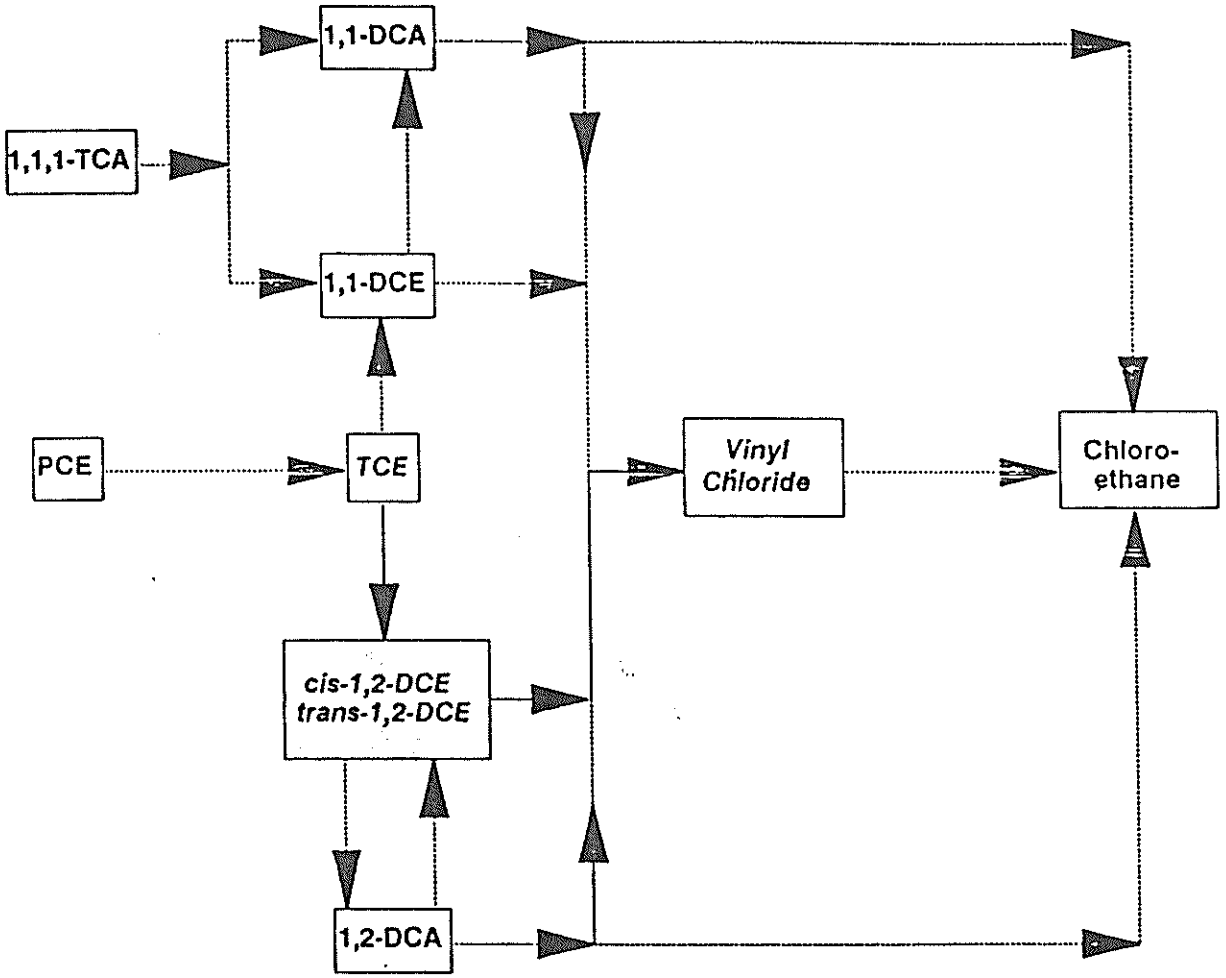
Figure 5-5 shows the potential biodegradation pathways for TCE and other chlorinated solvents (Dragun 1988). TCE and its degradation products observed at IFG are highlighted on Figure 5-1. The prevailing occurrence of 1,2-DCE and vinyl chloride in association with TCE suggests that *anaerobic* biodegradation of TCE (vs *aerobic*) is occurring (Dragun 1988; Rowland and Eisenberg 1989; Lanzarone and McCarty 1990). Therefore, the enhancement of the natural anaerobic biodegradation of TCE may be a viable remedial alternative for this compound (Rowland and Eisenberg 1989).

5.2.3 Regulatory Impact of Off-Site Sources of TCE

Because TCE and its degradation products are the principal VOCs observed in the groundwater beneath IFG (in terms of both their concentrations and spatial distribution), they represent a significant problem with respect to IFG's current NJPDES/DGW groundwater monitoring program. The available information on NAPC, combined with the southeast water flow and the historical absence of both (1) TCE usage at IFG, and (2) TCE in IFG's groundwater monitor wells MW-4, MW-5, MW-6 and MW-7, (which show the highest concentrations of contaminants associated with IFG's former sludge impoundments), clearly shows that an off-site source is responsible for the groundwater contamination at IFG. Similarly, the observed degradation products of TCE in local groundwater (1,2-trans-DCE and vinyl chloride) are also be attributable to the NAPC.

The data from both the NAPC and IFG sites implicate the NAPC operations as source of TCE contamination in the ground and surface waters. The NAPC, therefore, should bear the responsibility for investigation and remediating the presence of TCE and its degradation products. IFG should monitor NAPC investigations to ensure that upgradient releases of those contaminants migrating onto the IFG site are remediated.

FIGURE 5 - 5
Site Specific Degradation of TCE



CHAPTER 6

PRELIMINARY ASSESSMENT OF REMEDIAL ALTERNATIVES

It is LMS' understanding that IFG intends to take a proactive position with respect to the remediation of the limited groundwater contamination present in the UST area and the areas immediately surrounding the inactive sludge impoundments. Remedial alternatives for the UST and sludge impoundment areas will be determined by site-specific geologic and hydrogeologic factors, the concentrations of organics and metals in the groundwater to be treated, and the effluent limitations imposed on the discharge of the treated groundwater.

6.1 OVERVIEW OF REMEDIAL STRATEGIES

A successful groundwater remediation program must address two fundamental tasks:

1. Source reduction, remediation, or elimination
2. Plume capture and remediation

For the UST area, source reduction, remediation, or elimination might involve the location, removal, and disposal (or on-site treatment) of gasoline contaminated soil, vapor, and/or pockets of free product that may be trapped in the subsurface. Based on LMS' review of the previous investigations of the UST area, any or all of these nonaqueous phases may represent minor sources in the continued release of aqueous phase constituents of gasoline. Plume capture and remediation would involve the containment and remediation of the plume of aqueous phase constituents, such as the BTX components of gasoline. The most feasible means of capturing the plume of aqueous contaminants is the use of recovery (interceptor) wells (see below).

For the sludge impoundments, source reduction, remediation, or elimination might involve the removal and off-site disposal or incineration of the wastes contained in the impoundments. Another alternative to source reduction may be the design and construction of a lined, RCRA/NJDEP-approved, on-site disposal facility, and the subsequent transport

of the sludge from the existing impoundments to the new disposal facility. Subsequently, closure of both facilities could be pursued. Other alternatives include the *in-situ* bioreclamation or vitrification of the sludges in place, both of which are relatively new applications of state-of-the-art technologies. Yet another option would be the on-site destruction of this material with the use of a portable incinerator. The isolation of the sludge impoundments from the environment by using slurry walls or interceptor trenches is not recommended because of the poor performance record of such structures and the potential regulatory risk involved.

As discussed in previous sections, LMS' review of IFG's groundwater data suggests that the aqueous plume of contaminants associated with the impoundments is limited in terms of both its areal extent and the concentrations of the compounds observed. Therefore, the plume capture and remediation component of the sludge impoundments' remedial effort could be tied into the same treatment system(s) employed for the UST area (e.g., by routing the flow from interceptor wells around the impoundments to the treatment facility employed for the UST area).

6.2 ALTERNATIVES FOR GROUNDWATER REMEDIATION

The groundwater treatment technologies that are currently employed in environmental restoration projects can be divided into two major classes based on *where* the treatment of contaminated groundwater takes place:

1. *Pump and treat* systems, as the name implies, involve pumping contaminated groundwater from one or more recovery (interceptor) wells to a location above the ground surface and removing contaminants with a selected treatment system. The treated groundwater is either returned to the subsurface through one or more injection wells or is discharged as a sanitary or industrial wastewater.

2. *In situ treatment* systems involve the direct remediation of groundwater contamination in the subsurface. Bioremediation is the most common class of true *in-situ* treatment technologies. In general, bioremediation involves the introduction of carefully cultured microbes to the subsurface where contamination occurs. These engineered microbes are selected based on their ability to (1) metabolize (and therefore degrade) the organic contaminants

present in the subsurface and (2) survive in the subsurface in the face of direct competition with other microbes.

The major advantage of pump and treat systems is that with careful planning and design, capture of the aqueous phase plume often can be achieved rapidly. There is also great flexibility to design a groundwater treatment system to meet site-specific needs. Treatment units can be added, removed or modified, in parallel or in series, which permits the treatment of a wide range of contaminants, their concentrations and flow rates.

The major disadvantage of pump and treat systems is their operational cost, resulting from the actual operational life span of the system vs the design life of the system. The literature cites many case studies of pump and treat systems where their actual performance falls short of the projected remedial goals (Haley et al., 1991; Nyer, 1985; Nyer, 1990). The failure of many pump and treat systems to rapidly produce the desired reduction in the concentrations of groundwater contaminants has been largely attributed to the failure to acquire (and analyze) the information needed to properly design a given pump and treat system (Haley et al., 1991; Nyer, 1990). In addition, pump and treat systems only treat aqueous phase constituents; therefore, they are generally incapable of eliminating *non-aqueous* phase contaminants in the subsurface that continue to be sources of their aqueous-phase counterparts (Connor et al., 1989; Haley et al., 1991; Nielson-Cerquone et al., 1989; Nyer, 1985; Nyer, 1990). Satisfactory remediation of contaminants such as TCE, which are relatively insoluble and typically migrate as slugs of DNAPL, is especially difficult and often not achievable with standard pump and treat systems (Schmidtke, Mcbean and Rovers, 1987; Thomsen, 1989; Connor et al., 1989).

As discussed in Chapters 4 and 5, IFG's groundwater problems are relatively minor in comparison to the plume of TCE (and its degradation products) that has migrated onto and beneath their site from the NAPC. TCE and its degradation products are the most common VOCs present in the groundwater beneath IFG, and their prevalence suggests that DNAPL TCE may also be present. Given these conditions, great care should be incorporated into the selection and design of IFG's future groundwater remediation system(s) to limit the drawdown in the overburden and/or bedrock water-bearing zones so that as little additional TCE is pulled on site as possible. Therefore, the selection of the possible locations of IFG's future

interceptor wells and reinjection wells should be carefully evaluated during the planning and design phase of the remediation project.

The complications of the site's geology on the fate and migration of TCE, as well as its current abundance beneath IFG's property, may prove that the eventual treatment of TCE and its degradation products is an unavoidable consequence of IFG's remediation of their UST and sludge impoundment areas. Consequently, IFG should continue to explore the options available for the sharing of both the information and costs associated with their remedial efforts with the Naval Air Propulsion Center (NAPC).

6.3 OPTIONS FOR GROUNDWATER TREATMENT

IFG has several options regarding the type of groundwater remediation system that could be implemented for either the UST or sludge impoundment area. This section addresses the UST and sludge impoundment areas together, as it is anticipated that the remediation of both of these areas will require removal of organics and metals. An overview of the viable groundwater treatment technologies available to IFG is provided below.

6.3.1 Use of Existing Facilities for the Treatment of Groundwater

IFG operates a high-volume wastewater treatment (WT) facility on site for the treatment of process wastewaters. It would be to IFG's advantage to use this facility for the treatment of groundwater. LMS and IFG have discussed the excellent removals of VOCs, semivolatiles, and metals currently achieved by IFG's WT facility.

IFG's WT facility currently treats between 350,000 and 400,000 gal per day. Therefore, the additional volume of flow that would be contributed by groundwater pumped on site should be negligible. This point is substantiated by the following fact: IFG pumped ≈65,000 gal/day of contaminated groundwater into their WT facility under the guidance of NJDEP during the dewatering activities associated with the construction of their new oil/water separator system from late November 1990 through February 1991 (Appendix I). IFG observed no change in the quality of their WT effluent during this period.

Appendix I also includes representative chemical data on the quality of the groundwater pumped and treated during IFG's dewatering activities. LMS' review of this data suggests that the overall quality of the groundwater pumped during IFG's dewatering activities may be typical of that treated during a future groundwater remediation program. Therefore, IFG's use of their existing WT facility for the future treatment and remediation of groundwater on site may be a viable and cost-effective option. This option is especially attractive given the fact that IFG's WT facility would achieve removals of VOCs, semivolatiles and metals from groundwater. If in the future the WT facility is no longer needed to treat process water on site, the possibility of modifying the plant to receive only the groundwater flow should be evaluated.

In summary, the potential advantages related to IFG's use of their existing WT facility for groundwater treatment, as well as the pertinent technical considerations such as the use of tap water or treated effluent for groundwater recharge, should be fully evaluated. Issues that would need to be addressed include the capacity of the existing WT plant, the long-term operational forecast for the WT plant, and the modifications that would be required to IFG's industrial wastewater permit.

6.3.2 Metals Removal

Removal of metals from wastewater is usually accomplished by pH adjustment to a level at which the metal(s) of interest have minimum solubility. This could be accomplished with or without the addition of a polymer, followed by settling or filtration. Metals removal in IFG's WT facility is accomplished by raising the pH.

Lead appears to be the metal of major concern present in the UST area groundwater. Zinc and nickel are the principal metals of concern in the impoundment area. Manganese is present at the highest concentrations of any metal analyzed in association with IFG's DGW groundwater monitoring program. Manganese is present at average concentrations of 927.61 ppb in overburden and 1580.59 ppb in bedrock groundwater. This may indicate that iron is present at concentrations equal to or greater than those observed for manganese. As previously mentioned, manganese and iron (as well as copper and barium) are suspected to

be common natural constituents of the groundwaters that occur beneath IFG; therefore, the selection and design of a given metals treatment system should anticipate their persistence in the site's groundwater.

The presence of manganese and iron is important because they may significantly affect the selection of the remedial alternative for VOC removal, (depending on their concentrations). Iron is reported at concentrations of up to 218 ppm in unfiltered local groundwater in the FSI report on the NAPC facility (IT Corporation, 1989). These concentrations of iron would prohibit the effective use of a packed-column air stripper for VOC removal at IFG. Numerous cases of fouling and plugging of packed tower air strippers with ferrous hydroxide can be found in the literature on groundwater remediation (Nyer, 1985; Nyer, 1990; Wolf and Miller, 1989).

The two principal options available to IFG for metals treatment are (1) metals removal prior to VOC removal or (2) treatment for metals through the existing industrial wastewater treatment (WT) facility following VOC removal. The advantage of option (1) is that VOC removal is less complicated (see below). As previously discussed, the principal advantage of option (2) is that it would utilize IFG's existing WT plant, thereby offering opportunities for both cost savings and ease of implementation.

As part of the determination of the best flow scheme for metals and VOC removals, the treatment required for metals removal from the specific source areas must first be evaluated. Jar tests should be conducted on composite samples of the groundwater from each of the areas to be remediated. The jar tests would consist of pH adjustment and polymer addition at varying dosages. These tests would provide input on the treatment required to achieve the desired level of metals removal. Should it be determined that the conditions required for metals removal from groundwater in the UST or sludge impoundment areas are significantly different from those conducted at the on-site WT facility, then the combination of pumped groundwater with the process wastewater stream might not be feasible for metals removal. However, LMS' conversations with IFG personnel have suggested that the existing WT facility should be able to achieve the required objectives for metals removal from the site's groundwater.

6.3.3 VOC Removal

Air stripping is the most common method for removal of VOCs from pumped groundwater. Organics can also be removed by biological treatment, either *in-situ* or by pump and treat, and by a recently developed treatment technology called UV (ultraviolet) peroxidation. The advantages and disadvantages of these types of VOC removal technologies are discussed below, along with the conditions at IFG that make these treatment systems desirable or undesirable.

6.3.3.1 *Air Stripping.* Most of the organic contaminants present in the UST and sludge impoundment areas could effectively be removed from the groundwater by air stripping. However, semivolatile compounds, such as phenols, phthalates, fluorene, naphthalene, acenaphthene, and phenanthrene, would be particularly difficult to remove with air stripping.

Packed tower air strippers are generally the most efficient type of air stripper as they maximize mass transfer between the liquid and gas phases. However, a packed tower at the IFG site may potentially foul and clog with ferrous hydroxide and other settleable solids. This potential problem should be quantitatively evaluated by measuring the suspended solids and iron concentrations within the source areas' groundwater. Iron concentrations greater than 6-8 ppm should be reduced to below this level if a packed tower is to be used. At or below this range of iron concentrations, periodic acid rinsing of the tower would probably be required to prevent fouling and clogging of the packing. If it is determined that the iron and suspended solids concentrations are significantly greater than the range discussed above, an alternative method of air stripping should be considered. Possibilities include the use of a spray tower, a surface aeration system, or another process specifically designed to avoid operating problems associated with high levels of iron.

A spray tower is similar to a packed tower except that it does not contain a packing material. A stream of pumped groundwater is sprayed down into the tower through one or more nozzles attached near the top. As with a packed tower, an airstream is forced up from the base of the spray tower with a blower. The use of spray towers is less common and not

nearly as efficient as packed tower air stripping; however, it is a simple and attractive alternative where high iron concentrations are present.

A surface or mechanical aeration system consists of a tank which contains a mechanical aerator. The mechanical aerator creates contact between the liquid and vapor phases. Natural air supply across the top of the tank may be supplemented by blowers or fans to ensure that adequate air is provided to strip the VOCs. This system is also less efficient than a packed tower, though it avoids problems with iron fouling as the solids in the tank are kept in suspension by the mechanical aerator.

If an air stripping system were is selected for the reduction of VOC groundwater contamination at IFG, then off-gas treatment and the requirements for a NJDEP air permit would have to be evaluated. LMS' discussions with IFG personnel have indicated that these are likely requirements, as the air quality in the Trenton area has been designated as "severe" in terms on non-attainment of local goals for ozone levels (0.180-0.280 ppm). Activated carbon filters are commonly used for the treatment of off-gas.

6.3.3.2 *Ultraviolet (UV) Peroxidation.* A potentially promising alternative for VOC removal is the use of ultraviolet light and hydrogen peroxide to catalyze the chemical oxidation of organic contaminants in water. The advantage of ultraviolet peroxidation is that the organic contaminants are converted to carbon dioxide and water, as opposed to merely being transferred from the groundwater to the air as with air stripping. LMS' review of literature obtained from one manufacturer of a UV peroxidation system indicates that most of the organic compounds found at IFG have been successfully removed with this technique at other locations (Cheuvront et al., 1990). If feasible, the use of a UV peroxidation system would not only preclude the need to treat the off-gas, but may also destroy several semivolatile compounds which would otherwise be little affected by air stripping. Therefore, the potential technical advantages and cost savings of the use of a UV peroxidation system at IFG should be evaluated.

The concentration of iron and the overall turbidity of the groundwater remains a key factor in the determination of whether this type of system would be suitable for groundwater

remediation at IFG. High concentrations of solids impede the effectiveness of the UV light; therefore, removal of suspended solids and iron prior to the UV peroxidation treatment of organics might be required.

6.3.3.3 ***In Situ Bioremediation.*** As previously mentioned, bioremediation is the most common *in-situ* treatment technology for the mitigation of subsurface sources of organic contaminants aside from pump and treat. Although bioremediation of VOC groundwater contamination is a relatively new application in the field of groundwater restoration, it is based upon proven technology borrowed from the wastewater treatment industry--i.e. a stimulated stock of microbes is used to degrade organic compounds in water (Nielson-Cerquone et al., 1989). The available literature on bioremediation suggests that bacteria are able to metabolize and degrade many of the halogenated alkanes and alkenes commonly associated with industrial solvents, as well as with aromatic and aliphatic organic compounds associated with petroleum products (Nielson-Cerquone et al., 1989; Weston and U. Mass., 1988).

Currently, the most practical application of in-situ bioremediation technology to groundwater remediation is in combination with a standard pump and treat system. Such an application at IFG might involve the pumping of site groundwater to a treatment tank, inoculation of the groundwater in the tank with selected strains of bacteria, nutrients and catalysts, and the re-injection of the resulting "cocktail" into the subsurface. The bacterial cocktail can infiltrate and subsequently remediate portions of the saturated subsurface that are either not in hydraulic connection with interceptor wells or are unaffected by their influence, such as fine-grained strata in the overburden and hydraulically isolated pockets of contaminants in both the overburden and bedrock. The literature on such applications suggests that the remediation of organics in groundwater with standard pump and treat technology can be greatly enhanced by *in-situ* bioremediation in terms of both (1) the rapid reduction of observed contaminant concentrations and (2) reduction of the operational life of the entire treatment system (Nielson-Cerquone et al., 1989; Roberts et al., 1989). Because of the potential benefits of greater remedial efficiency and reduced cost offered by this technology, LMS recommends that it be further evaluated for application to the IFG-Trenton site, especially in terms of remediation of the UST area groundwater.

6.4 Conceptual Design and Pilot Test

Prior to the final selection, design, and implementation of a groundwater remediation system for IFG-Trenton, LMS suggests that a detailed review of the remedial alternatives be undertaken as part of a conceptual design project. Additional information concerning the site's geology, upgradient influences on groundwater quality, the compound and site-specific standards for cleanup (which have yet to be negotiated with NJDEP), and the solids characteristics of IFG's groundwater (particularly iron concentrations) is needed to facilitate the review of remedial alternatives and conceptual design of a treatment system. Jar tests for metals removal should also be conducted.

Subsequent to the conceptual design phase, it may be advisable to conduct pilot tests of the selected remedial technologies. If a pump and treatment system is selected, several key factors should be considered, such as the number and geometric layout of interceptor and reinjection wells and their associated pumping rates. Care should be taken to minimize the amount of TCE and its degradation products drawn on-site from the NAPC by a pump and treat approach. Likewise, it would be advisable to conduct bench and/or pilot scale tests of a selected bioremediation technology concurrent with the evaluation of the alternatives for pump and treat. For the UST area, bioremediation may be the most attractive option for groundwater remediation. In the event that the use of a packed tower for air stripping appears to be feasible, a pilot test might not be necessary, (except to evaluate potential fouling or clogging problems), as reliable design information is available "off the shelf." If high iron and/or solids concentrations are present and a surface aeration system or spray tower appears to be a better remedial alternative, it would be advisable to conduct a pilot stripping test to better define the attainable VOC removal efficiency of a full-scale treatment facility. Similarly, if IFG determines that UV peroxidation is the favorable alternative for organics removal, LMS suggests that a pilot test first be conducted.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER ACTION

7.1 CONCLUSIONS

Based on the results of this investigation at IFG, several conclusions can be made concerning the contaminant hydrogeology of this site within the context of regional influences on groundwater occurrence, movement, and quality:

- The results of this investigation support the separation of the groundwater issues discussed above. The separation of these groundwater issues (in terms of source areas) are clearly reflected in the spatial distributions of their associated compounds.

- Substantial information exists to identify the Naval Air Propulsion Center (NAPC) upgradient of IFG as the source of TCE and its degradation products. TCE and its principal anaerobic degradation products (1,2-trans-DCE and vinyl chloride) are the principal VOCs found in the groundwater beneath IFG. Other VOCs, metals, and semivolatile compounds are also suspected to be migrating downgradient from the NAPC.

- TCE and its degradation products have not been observed in IFG's overburden wells MW-4, MW-5, MW-6 and MW-7. As these wells typically contain the highest concentrations of the compounds attributed to IFG's former sludge impoundments, this observation further supports an off-site source of TCE and its degradation products.

- The potential quantities of TCE lost to the subsurface at the NAPC could be significantly greater than the 1700 gal postulated in the Initial Assessment Study reviewed by LMS. The presence of DNAPL TCE in the subsurface could preclude the timely remediation of total VOCs in the area. The potential impact of this issue on IFG's goals for future remedial activities needs to be evaluated further.

- LMS' review of the deep monitor well boring logs from the UST area suggests that the air-hammer installation method used may have created "blowouts" in the Stockton Formation, and therefore irregularly shaped boreholes. The presence of vertically interconnected voids in the grout of these deep UST wells is indicated by the elevated concentrations of TCE and its degradation products observed in these deep wells. Given the potential presence of DNAPL TCE on top of the competent bedrock surface, its downward migration through voids associated with IFG's deep UST wells could be cross-contaminating deeper portions of the Stockton. We recommend grouting and closing the UST wells that are open beneath a depth of ≥50 ft BGS.

- Fine-grained strata are present in the overburden, although they are not laterally continuous. Therefore, these strata do not appear to hydraulically isolate the thin veneer of overburden from the fractured bedrock zone. This observation, coupled with the potentially high horizontal conductivity of the weathered rock zone, may explain the widespread occurrence of "sinking" contaminants such as TCE.

- The 1 to 4-ft thick fractured bedrock zone situated between the overburden and competent bedrock appears to be the dominant groundwater-bearing zone at the IFG site. Groundwater appears to drain rapidly into this zone from the overburden, which may explain the relatively sporadic occurrence of groundwater in the "true" overburden. Many of the overburden monitor wells are completed to the top of competent bedrock, and are therefore hydraulically connected to the fractured rock zone. Therefore, the unconsolidated overburden and fractured rock zone function as one hydrogeologic unit. Groundwater flow in this unit appears to have discreet southern and eastern components of flow.

- Groundwater flow in the fractured rock zone is expected to follow the geometric surface of the uppermost competent Stockton bedrock. The geometry of the competent bedrock surface is poorly understood. The further evaluation of the geometry of the bedrock surface and its control on the fate and migration of contaminants in local groundwater is crucial to the design of an effective groundwater remediation system at IFG.

- Gold Run is suspected to follow the north-south trace of a normal fault. A complex system of joints and fractures is expected in the bedrock on either side of Gold Run, which may explain the complicated interaction of Gold Run with the site's groundwater observed during this investigation.

- The structural deformation of Stockton beneath IFG and the suspected presence of one or more normal faults suggests that there is a strong structural influence on groundwater occurrence and movement in this area.

- Groundwater observed in the competent bedrock appears to be under semiconfined conditions. This is supported by the observations of (1) different head measurements obtained from the overburden and bedrock well couplets (MW-1/MW-1A, MW-7/MW-7A, and MW-15/MW-15A) and (2) observations of rapid and substantial (pressure) head increases in MW-16 in response to storms, and slow dissipation of this head buildup.

- Significant interaction of the site's groundwater with Gold Run occurs on site. Interaction was observed to increase from north to south, and to be greatest in the vicinity of MW-13. Based on LMS' review of both IFG's hydrographic and water quality data, the reach of Gold Run adjacent to MW-13 is suspected to be a zone of regional groundwater discharge. This conclusion is further supported by observations of increasing concentrations of off-site contaminants (i.e. TCE, 1,2-trans-DCE and vinyl chloride) in groundwater towards the non-industrial portions of IFG's property to the south and east.

- The "episodic" migration of certain contaminants (such as DNAPL TCE) in response to storm events may be an important mechanism. This is suggested by the erratic temporal variation observed for TCE and DCE in MW-13, which does not appear to correlate with the more regular seasonal variation observed for MW-1A and MW-11.

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