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MIDDLESEX SAMPLING PLANT
ENVIRONMENTAL REPORT FOR
CALENDAR YEAR 1989

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By

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SUMMARY ASSESSMENT
ENVIRONMENTAL COMPLIANCE ACTIVITY
U.S. DEPARTMENT OF ENERGY
FORMERLY UTILIZED SITES REMEDIAL ACTION PROGRAM
MIDDLESEX SAMPLING PLANT

BACKGROUND AND OVERVIEW

To evaluate the environmental compliance record of the Middlesex Sampling Plant (MSP), managed as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP), it is necessary to describe the history of the site.

The Manhattan Engineer District (MED) established MSP in 1943. The facility was used for sampling, storage, and/or shipment of uranium, thorium, and beryllium ores. All ores received at the facility were handled in a similar manner, including thawing (if necessary), drying, crushing, and screening. Samples were taken for assay from collection hoppers beneath the screens. The ores were subsequently packaged, weighed, and shipped to processing facilities.

Operation of MSP was terminated in 1955 by the U.S. Atomic Energy Commission (AEC), successor to MED. Later, AEC used the site for storage and limited sampling of thorium residues. All AEC activities at MSP ended in 1967. On-site structures were decontaminated, and the site was certified for use with no radiological restrictions under criteria in effect at that time.

In 1968, AEC returned the MSP site to the General Services Administration, which transferred the property to the Department of the Navy. The site served as a reserve training center for the U.S. Marine Corps from 1969 to 1979. MSP was returned to the custody of the U.S. Department of Energy (DOE) in 1980. That same year DOE initiated remedial action to clean up properties in the vicinity of MSP; the cleanup continued into 1981. Approximately 27,000 m^3 (35,000 yd^3) of contaminated soil from these removal

actions were transported to MSP, where an asphalt pad was constructed as a base for an interim storage area.

Operations at the Middlesex Municipal Landfill (MML), a vicinity property of MSP, began in the mid-1940s. In 1948, soil contaminated with pitchblende was removed from MSP and placed on top of existing fill at MML. Subsequent landfill operations resulted in varying depths of cover material being placed over the contaminated material. The landfill has not been used for solid waste disposal since 1974.

A second storage pad at MSP was constructed in 1984 to accommodate the materials excavated from MML during that year. The pad is enclosed with concrete curbing. A geomembrane is attached to the curbing and covers the stored materials.

In 1986, removal actions at MML were completed. Approximately 50,000 m^3 (66,000 yd^3) of contaminated materials were excavated from the landfill in 1984 and 1986. The excavation was backfilled with clean soil, and the area was seeded.

During its history, MSP has been subject to evolving federal and state environmental regulations. The following summary describes compliance requirements as they currently exist.

Clean Air Act (CAA) and National Emission Standards for Hazardous Air Pollutants (NESHAPs)

MSP does not have any state or federal air permits. As a non-operating facility, only Subparts H and Q of NESHAPs are applicable. Compliance with the non-radon radionuclide standard in Subpart H will be determined by evaluating the site using a computer model (e.g., AIRDOS-PC) approved by the Environmental Protection Agency (EPA). A strategy for determining compliance with the radon flux standard in Subpart Q was submitted to EPA. Comments were received from EPA on the proposed compliance strategy on April 19, 1990. The comments require minor modifications to the compliance strategy. Radon flux measurements of the pile will begin by July 18, 1990, absent further comments from EPA.

DOE Orders for Radionuclide Releases

Site releases must comply with specific DOE orders that place quantitative limits, called derived concentration guides (DCGs), and dose limits for radiological releases from DOE facilities. Results of environmental monitoring conducted in 1989 show that MSP is in compliance with DOE orders.

Clean Water Act (CWA)

MSP does not have any state or federal water permits. An environmental compliance assessment conducted by Oak Ridge National Laboratory (ORNL) in October 1989 did not find any deficiencies under the CWA. However, an inspection conducted on December 7, 1989, by the New Jersey Department of Environmental Protection (NJDEP) resulted in the issuance of a notice of violation (NOV) for a non-permitted point-source discharge of stormwater. The NOV was resolved on January 19, 1990, by submission of a permit application for the discharge. NJDEP has not yet acted on the application.

Resource Conservation and Recovery Act (RCRA)

RCRA-regulated waste is not present at MSP. Additionally, an environmental compliance assessment conducted by ORNL in October 1989 did not find any deficiencies under RCRA.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

MSP is not on the National Priorities List. Remediation of the site will be managed by DOE under the authority of the Atomic Energy Act of 1954.

Toxic Substances Control Act (TSCA)

TSCA-regulated waste is not present at MSP. The environmental compliance assessment of the site by ORNL did not find any deficiencies under TSCA.

National Environmental Policy Act (NEPA)

In the past, compliance with NEPA has been accomplished through the use of action description memoranda and corresponding memoranda-to-file. Actions taken to date have been determined to have no significant impact on the environment. Compliance with NEPA for site remedial actions will be accomplished by incorporating those elements required by an environmental assessment into the format of the CERCLA remedial investigation/feasibility study.

ABSTRACT

The environmental monitoring program, which began in 1980, was continued in 1989 at the former Middlesex Sampling Plant (MSP) site, located in the Borough of Middlesex, New Jersey. The MSP site is part of the Formerly Utilized Sites Remedial Action Program (FUSRAP), a Department of Energy (DOE) program to decontaminate or otherwise control sites where residual radioactive materials remain either from the early years of the nation's atomic energy program or from commercial operations causing conditions that Congress has authorized DOE to remedy. The environmental monitoring program is being conducted by Bechtel National, Inc. (BNI), project management contractor for FUSRAP.

The monitoring program at MSP measures radon concentrations in air; external gamma radiation levels; and uranium and radium concentrations in surface water, groundwater, and sediment. Additionally, several nonradiological parameters are measured in groundwater samples. To verify that the site is in compliance with the DOE radiation protection standard (100 mrem/yr) and to assess its potential effect on public health, the radiation dose was calculated for a hypothetical maximally exposed individual. Based on the conservative scenarios described in the report, this hypothetical individual at MSP would receive an annual external exposure equivalent to 2.3 percent of the DOE radiation protection standard. This is approximately equivalent to the exposure a person receives during one flight from New York to Los Angeles because of the greater amounts of cosmic radiation at higher altitudes. The cumulative dose to the population within an 80-km (50-mi) radius of the site that results from radioactive materials present at the MSP is indistinguishable from the dose that the same population receives from naturally occurring radioactive sources.

Results of the 1989 monitoring show that MSP is in compliance with applicable DOE radiation protection standards.

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(continued)

1.0 INTRODUCTION

This report presents the findings of the environmental monitoring program conducted in the area of the Middlesex Sampling Plant (MSP) site during calendar year 1989. The first environmental monitoring report for this site reported data for 1980, 1981, and 1982; data for subsequent years have been reported annually. The site is part of the United States Department of Energy (DOE) Formerly Utilized Sites Remedial Action Program (FUSRAP) and is located in the Borough of Middlesex, Middlesex County, New Jersey, as shown in Figure 1-1.

1.1 LOCATION AND DESCRIPTION

The MSP site occupies 3.9 ha (9.6 acres). As shown in Figure 1-2, there are four buildings on the site, which is surrounded by a 2.1-m- (7-ft-) high chain-link fence. Most of the site is paved with asphalt. MSP is currently used for interim storage of contaminated soils excavated from vicinity properties, including the Middlesex Municipal Landfill (MML). Figure 1-3 is an aerial photograph of the site. At the completion of remedial action at MML in 1986, 50,748 m^3 (66,372 yd^3) of contaminated soils were stored at MSP. The interim storage pad constructed at the MSP for the soil excavated from MML during the 1984 and 1986 remedial action activities includes a leachate collection system to preclude release of contaminants from the stored material to waters in the area.

The site slopes gently from approximately 18 m (60 ft) above mean sea level (msl) on the northern side to 15 m (50 ft) above msl on the southern side. Soils at MSP are silty to sandy loams with thickness over bedrock ranging from 0.46 to 2.4 m (1.5 to 8.0 ft). All on-site surface water is conveyed via an underground drainage system to a settling basin and then to the easement ditch south of the site that discharges into a small brook known as Main Stream.

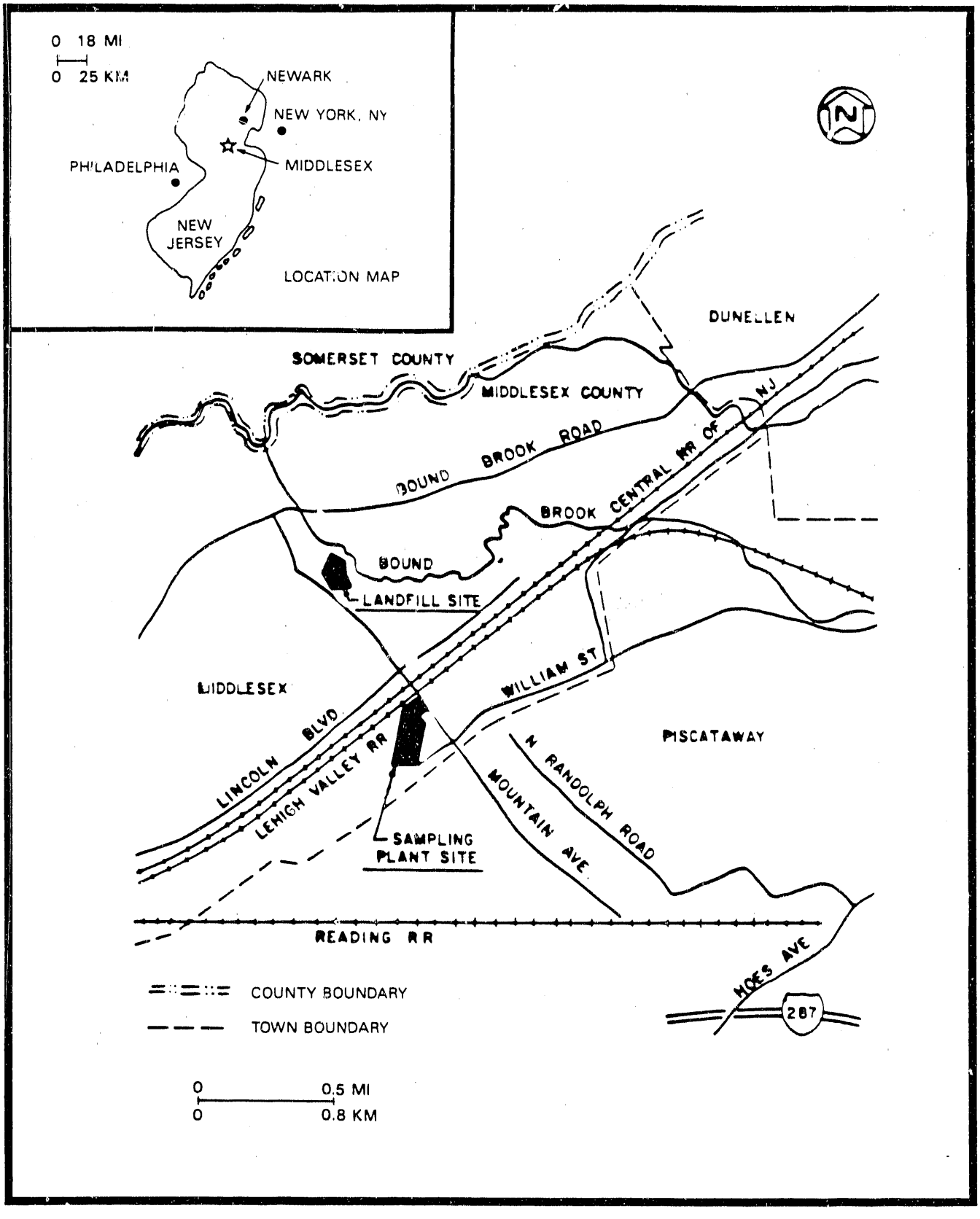

FIGURE 1-1 LOCATION OF MSP

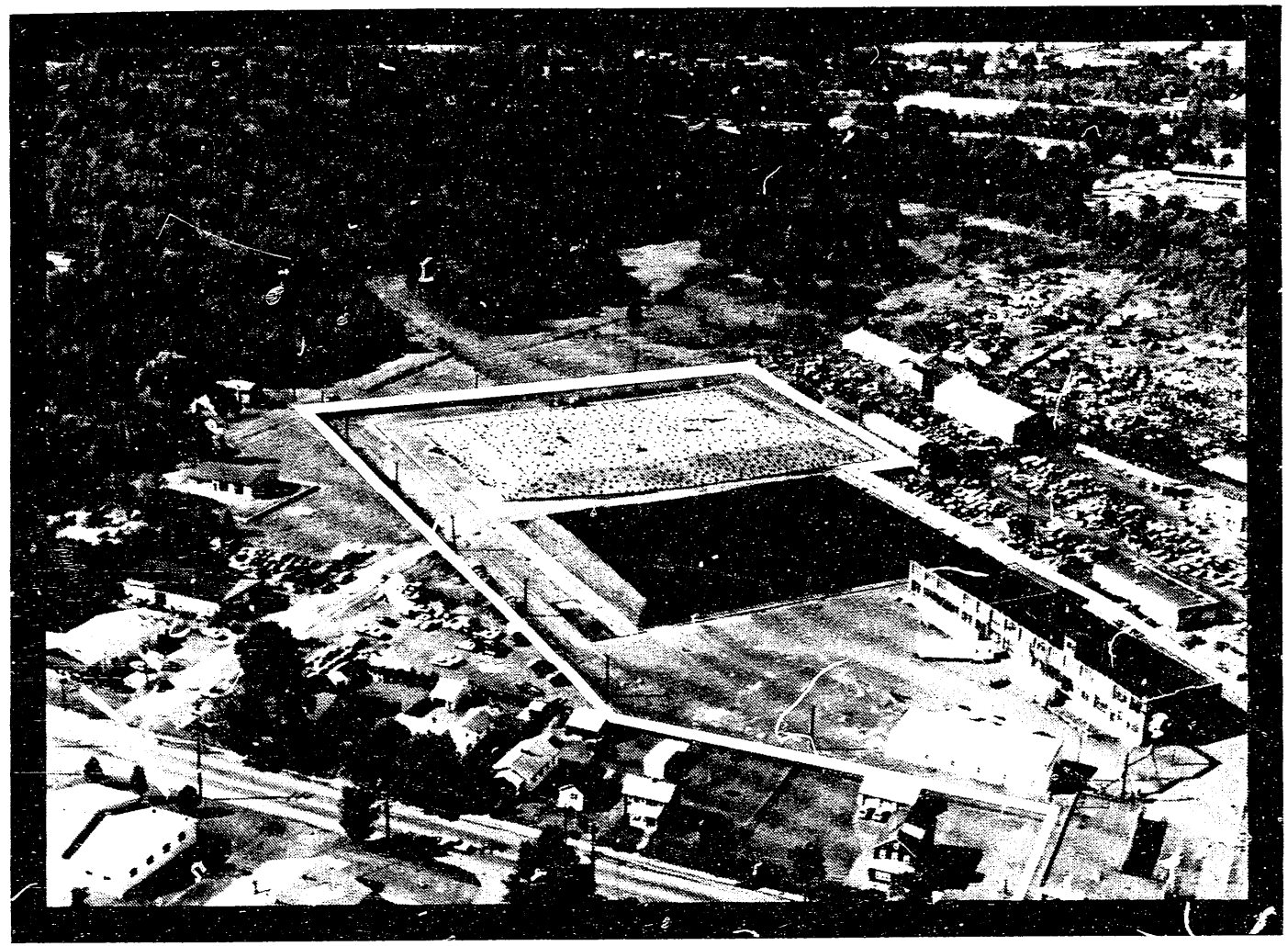

FIGURE 1-3 AERIAL VIEW OF MSP

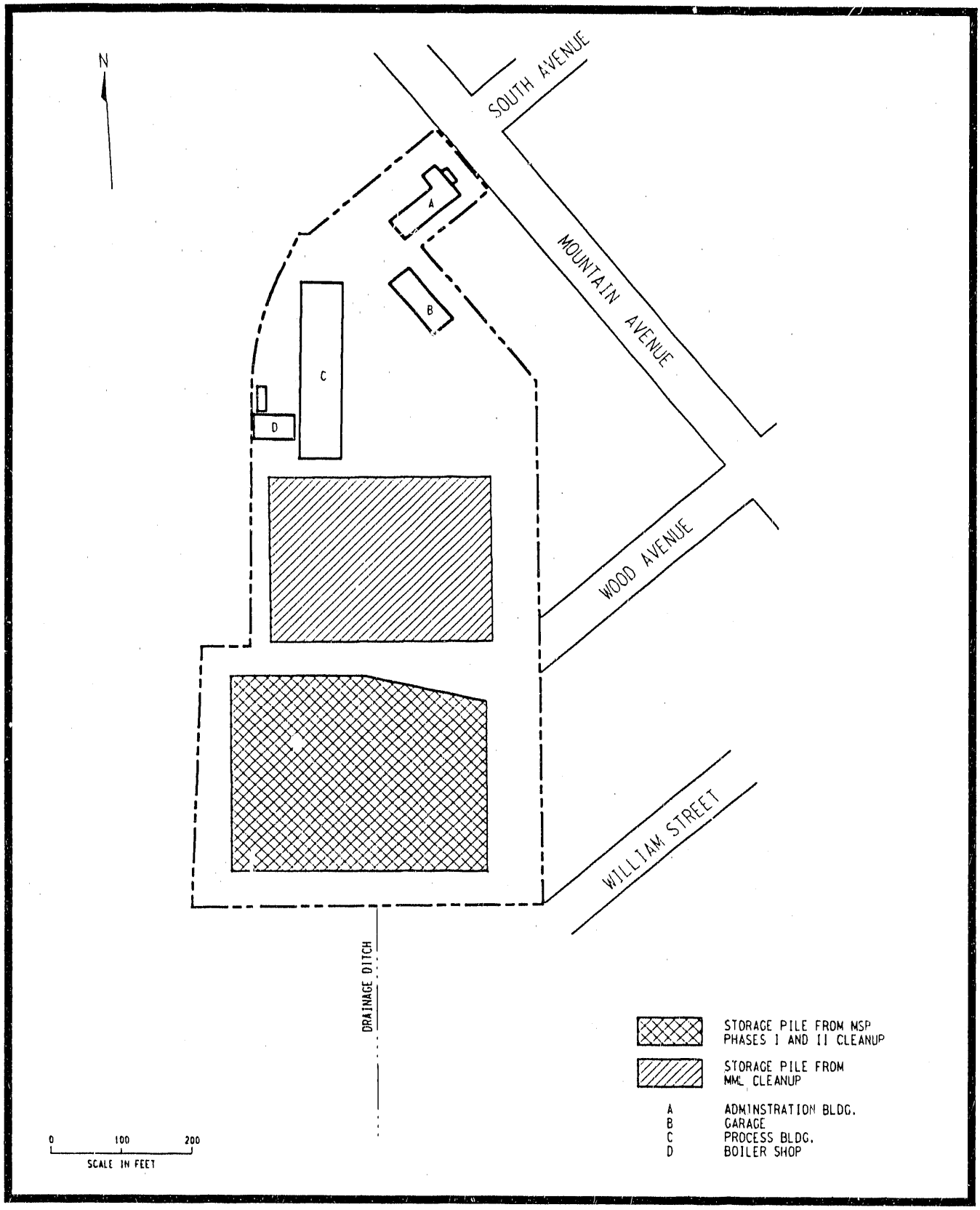

FIGURE 1-2 MAP OF THE MSP SITE

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The Brunswick formation is the predominant bedrock unit in the MSP vicinity; it is a major aquifer in the western part of Middlesex County and adjoining Essex County. Numerous private water supply wells are located within 1.6 km (1 mi) of MSP. A public well field, Sebrings Mill well field, lies 2 km (1.25 mi) northwest of MSP.

The average annual daily maximum temperature for the Middlesex area is 16.9°C (62.5°F), and the average daily minimum is 7.33°C (45.2°F). The highest average monthly temperature is 29.8°C (85.6°F) (July), and the lowest is -4.28°C (24.3°F) (January). Average annual precipitation is 107 cm (42 in.) with an average annual snowfall of 69.85 cm (27.5 in.) (Ref. 1) As shown in Figure 1-4, winds in the area blow predominantly from the southwest at a mean speed of 16 km/h (10 mph).

Approximately 15 million people reside within 80 km (50 mi) of Middlesex. The 1980 populations of Middlesex and Piscataway were 13,480 and 42,233, respectively; they are expected to increase over the next 10 to 15 years (Ref. 2).

As shown in Figure 1-5, land use in the vicinity of MSP is primarily residential and industrial. An expanse of vacant land borders the southern end of the site.

1.2 SITE HISTORY

The Manhattan Engineer District (MED) established MSP in 1943. The facility was used for sampling, storage, and/or shipment of uranium, thorium, and beryllium ores. All ores received at the facility were handled in a similar manner, including thawing (if necessary), drying, crushing, and screening. Samples were taken for assay from collection hoppers beneath the screens. The ores were subsequently packaged, weighed, and shipped to processing facilities.

Operation of MSP was terminated in 1955 by the Atomic Energy Commission (AEC), successor to the MED. Later, AEC used the site for storage and limited sampling of thorium residues. All AEC

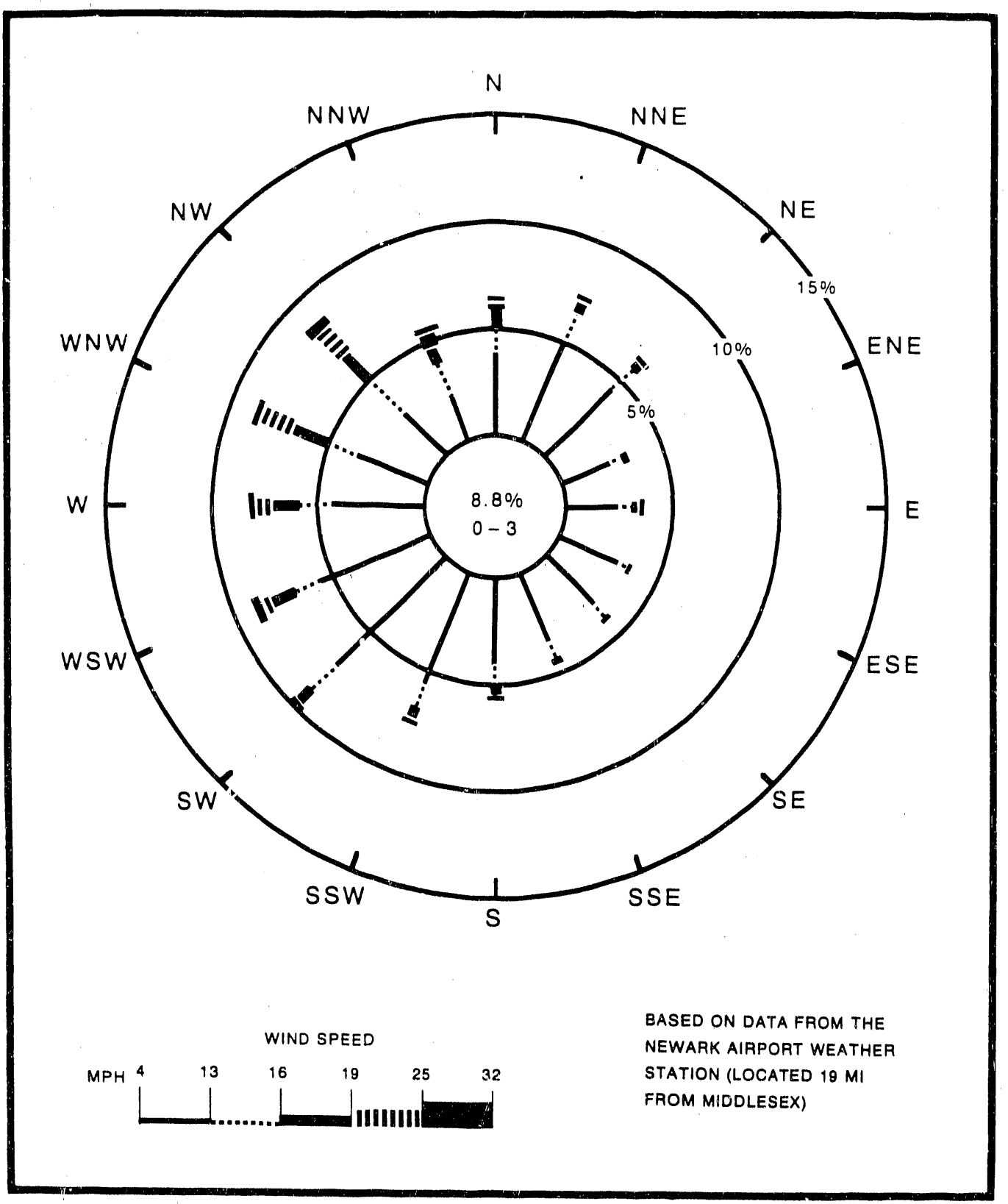
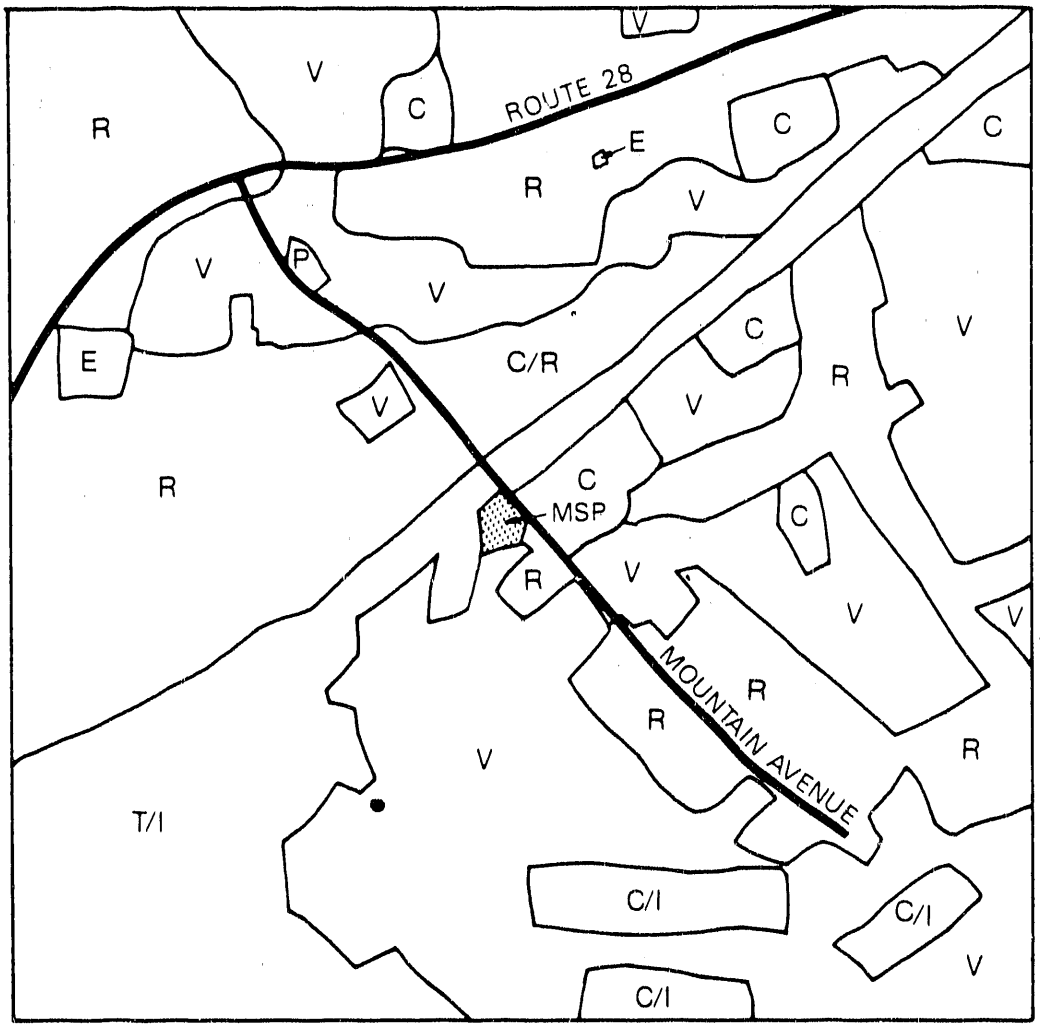


FIGURE 1-4 ANNUAL WIND ROSE FOR MSP



BASED ON AERIAL PHOTOGRAPHS, SITE VISITS, AND USGS TOPOGRAPHIC MAPS, 1:24000 SCALE, PLAINFIELD NJ QUADRANGLE, (PHOTO REVISED 1981) AND BOUND BROOK, (PHOTO REVISED 1970)

R RESIDENTIAL	C/I COMMERCIAL/INDUSTRIAL
C COMMERCIAL	T/I TRANSPORTATION/INDUSTRIAL
C/R MIXED RESIDENTIAL COMMERCIAL	V VACANT
P PUBLIC	E EDUCATIONAL

0 0.5 MI
0 0.8 KM

FIGURE 1-5 GENERALIZED LAND USE IN THE VICINITY OF MSP

activities at MSP ended in 1967. On-site structures were decontaminated, and the site was certified for unrestricted use under criteria in effect at that time.

In 1968, AEC returned the MSP site to the General Services Administration, which transferred the property to the Department of the Navy. The site served as a reserve training center for the U.S. Marine Corps from 1969 to 1979. MSP was returned to DOE custody in 1980. That same year DOE initiated remedial action to clean up properties in the vicinity of MSP, and the cleanup continued into 1981. Approximately 27,000 m^3 (35,000 yd^3) of contaminated soil from these remedial actions was transported to MSP, where an asphalt pad was constructed as a base for an interim storage area.

Operations at MML began in the mid-1940s. In 1948, dirt contaminated with pitchblende (high-grade uranium ore) was removed from MSP and placed on top of the existing fill at MML. Subsequent landfill operations resulted in varying depths of cover material being placed over the contaminated material. The landfill has not been used for solid waste disposal since 1974.

Two radiological surveys had indicated that the portion of the MML site requiring remedial action covered about 0.2 ha (0.5 acre) (Refs. 3, 4). Excavation of radioactively contaminated material from MML began in 1984; approximately 12,000 m^3 (16,000 yd^3) of contaminated soils were transported to MSP for interim storage. This excavation and subsequent investigations indicated that the contaminated area covered approximately 1.2 ha (3 acres).

A second storage pad was constructed at MSP in 1984 to accommodate the materials excavated from MML during that year. The pad is enclosed with concrete curbing to prevent migration of the stored materials. A geomembrane is attached to the curbing and was used to cover the stored materials whenever remedial action was not in progress. Table 1-1 lists the volumes and sources of the materials placed on the storage pads by year of emplacement and indicates the total volume of contaminated material presently stored at MSP.

TABLE 1-1

VOLUMES OF CONTAMINATED SOIL

ON MSP STORAGE PADS

Date and Source	Volume (m^3)[a]	Volume (yd^3)
1980 (Phase I) MSP Cleanup	7,203	9,421
1981 (Phase II) MSP Cleanup	19,681	25,742[b]
1984 MML Cleanup (Second Storage Pad)	11,942	15,620
1986 MML Cleanup (Extended Second Storage Pad)	11,919	15,589
Total on Storage Pads	50,745	66,372

[a] Numbers given in earlier reports were incorrect as a result of conversion error; they have been corrected, as reflected here.

[b] BNI (Ref. 5).

During 1985, site preparation work was conducted at MSP and MML in preparation for resuming remedial actions initiated in 1984. Work at MSP included the construction of a further extension to the storage area to accommodate material to be excavated from MML during 1986.

In 1986, remedial actions at MML were completed with the removal of the last 11,919 m^3 (15,620 yd^3) of contaminated soil. The excavation was backfilled with clean soil, and the area was seeded. The environmental monitoring program at MML was terminated because the site was remediated and returned to the Borough of Middlesex in December 1987.

There are no continuing commercial, industrial, or remedial activities at MSP; therefore, there are no airborne radioactive effluents from the site, and waterborne radioactive effluents are limited to extremely low concentrations in surface drainage.

1.3 HYDROGEOLOGICAL CHARACTERISTICS OF THE SITE

The two groundwater systems monitored have been designated "shallow" and "deep" in previous environmental monitoring reports (Refs. 6 through 12). In this report, the terms "shallow" and "deep" are replaced with "upper" and "lower," respectively. Groundwater monitoring wells (Figure 1-6) were installed at the MSP site in two phases by Roy F. Weston, Inc.--Phase I in 1980 and Phase II in 1981. A summary of well construction information is shown in Tables 1-2 and 1-3. Further background information on site geology and hydrogeology can be found in Ref. 13. See Appendix E for examples of well construction details (Ref. 14).

The hydrogeological characteristics of MSP in 1989 remain unchanged from 1988, though the database are sporadic. Water level readings were obtained quarterly in 1988 and scheduled weekly in 1989 but were collected only from March to August and October to December.

Readings for January, February, and September were inadvertently omitted from the database.

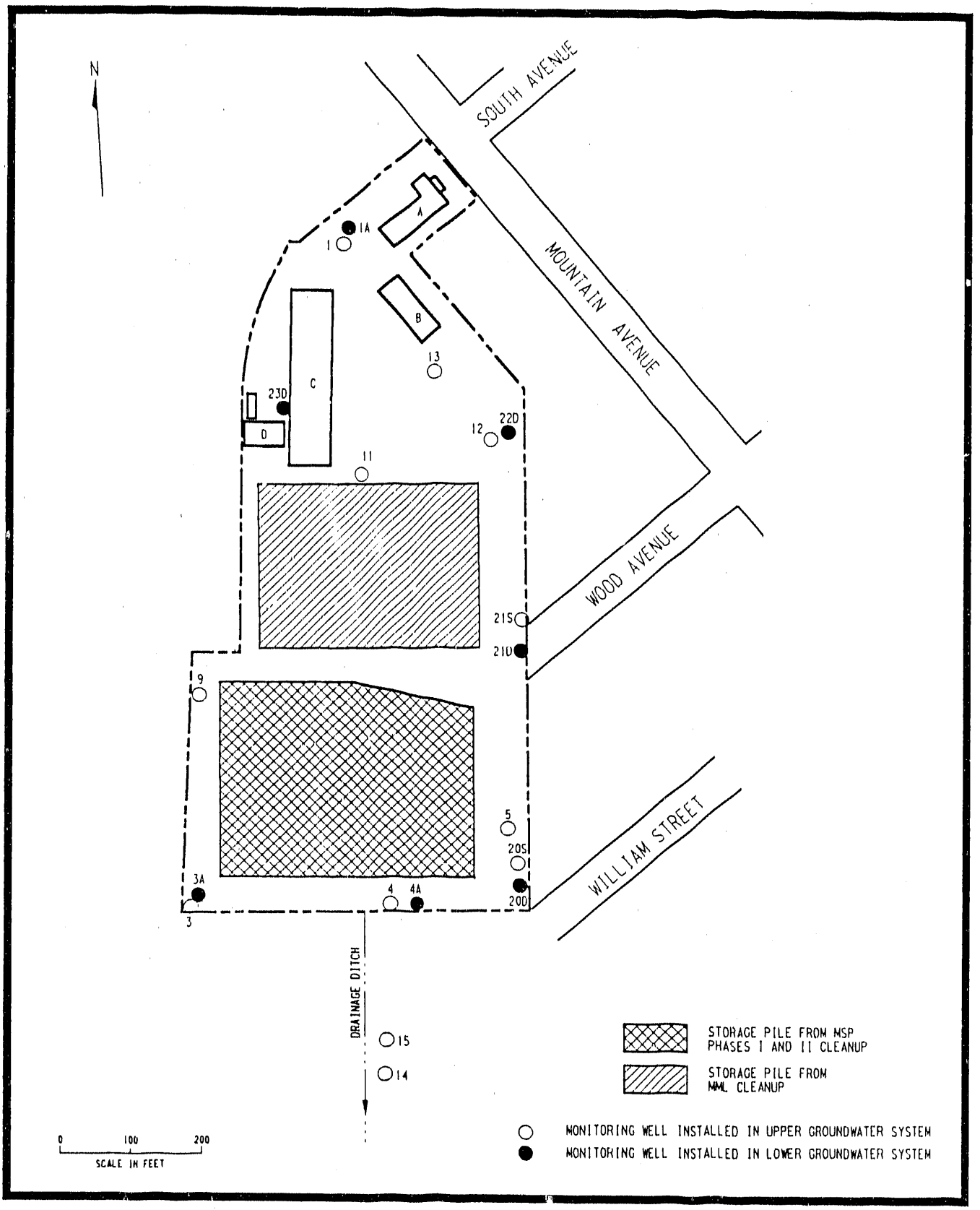


FIGURE 1-6 GROUNDWATER MONITORING WELL LOCATIONS AT MSP

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TABLE 1-2

MSP PHASE I MONITORING WELL CONSTRUCTION SUMMARY[a]

Well Number	Completion Date	Total Depth [m (ft)]	Screened or Open Interval Below Ground [m-m (ft-ft)]	Construction Material[b]
1	May 1980	3.05 (10.0)	1.1 - 3.05[c] (3.5-10.0)	PVC[d]
1A	May 1980	15.3 (50.0)	Open[c]	PVC[d]
3	May 1980	3.05 (10.0)	0.30 - 3.05[c] (1.0-10.0)	PVC[d]
3A	May 1980	15.3 (50.0)	Open[c]	PVC[d]
4	May 1980	3.05 (10.0)	0.50 - 3.05[c] (1.5-10.0)	PVC[d]
4A	May 1980	9.2 (30.0)	Open[c]	PVC[d]
5	May 1980	3.05 (10.0)	1.1 - 3.05 (3.5-10.0)	PVC
9	May 1980	3.05 (10.0)	0.0 - 3.05 (0.0-10.0)	PVC
11	May 1980	3.05 (10.0)	0.30 - 3.05 (1.0-10.0)	PVC
12	May 1980	3.05 (10.0)	0.30 - 3.05 (1.0-10.0)	PVC
13	May 1980	3.05 (10.0)	0.9 - 3.05 (3.0-10.0)	PVC
14	May 1980	4.6 (15.0)	1.2 - 4.6 (4.0-15.0)	PVC
15	May 1980	1.5 (5.0)	0.0 - 1.5 (0.0- 5.0)	PVC

[a]Wells installed by Roy F. Weston, Inc.

[b]PVC - polyvinyl chloride.

[c]Open at total depth; no documentation for top of interval.

[d]PVC conductor in overburden; open hole in bedrock.

TABLE 1-3

MSP PHASE II MONITORING WELL CONSTRUCTION SUMMARY[a]

Well Number	Completion Date	Total Depth [m (ft)]	Screened Interval Below Ground [m-m (ft-ft)]	Construction Material
20D	July 1981	15.3 (50.0)	12.2 - 15.3 (40.0-50.0)	PVC[b]
20S	July 1981	3.05 (10.0)	0.90 - 3.05 (3.0-10.0)	PVC
21D	July 1981	15.3 (50.0)	12.2 - 15.3 (40.0-50.0)	PVC
21S	July 1981	3.05 (10.0)	0.9 - 3.05 (3.0-10.0)	PVC
22D	July 1981	15.3 (50.0)	12.2 - 15.3 (40.0-50.0)	PVC
23D	July 1981	15.3 (50.0)	12.2 - 15.3 (40.0-50.0)	PVC

[a]Wells installed by Roy F. Weston, Inc.

[b]PVC - polyvinyl chloride.

1.3.1 Upper Groundwater System

The upper groundwater system is an unconfined saturated zone located approximately 0.6 to 3.0 m (2 to 10 ft) below the ground surface. Wells installed in this system are screened in the weathered, fissile Brunswick shale at depths of 1.5 to 4.6 m (5 to 15 ft). Groundwater level elevations measured in 1989 for each shallow well are shown as hydrographs in Figures 1-7, 1-8, and 1-9. Precipitation records for the site are also shown beneath each hydrograph.

The hydrographs for wells in the upper groundwater system do not indicate any seasonal variation in water levels. This observation can be confirmed when a complete cycle of annual measurements is taken. Correlation with precipitation events is slight to none, indicating either that no surface recharge takes place on the site, or that the upper groundwater system reaches equilibrium rapidly after a precipitation event.

The slope and flow direction of the upper groundwater system were determined from water table surface maps. (The water table, or potentiometric surface, is defined as the level to which water will rise in a tightly cased well. Delineation of the potentiometric surface of an aquifer indicates groundwater slope and flow direction.) The general direction of flow is from north to south, as shown on two potentiometric surface maps (Figure 1-10 for April and Figure 1-11 for December). The shape of the contours suggests that the potentiometric surface represents a subdued reflection of the site topography (Ref. 13). The gradient of the potentiometric surface for both sampling dates is on the order of 0.01, which represents no change from conditions observed in 1988 (Ref. 12).

1.3.2 Lower Groundwater System

The potentiometric surface of the confined lower groundwater system is approximately 2.4 to 9.1 m (8 to 30 ft) below the ground surface. Wells installed in the lower groundwater system monitor

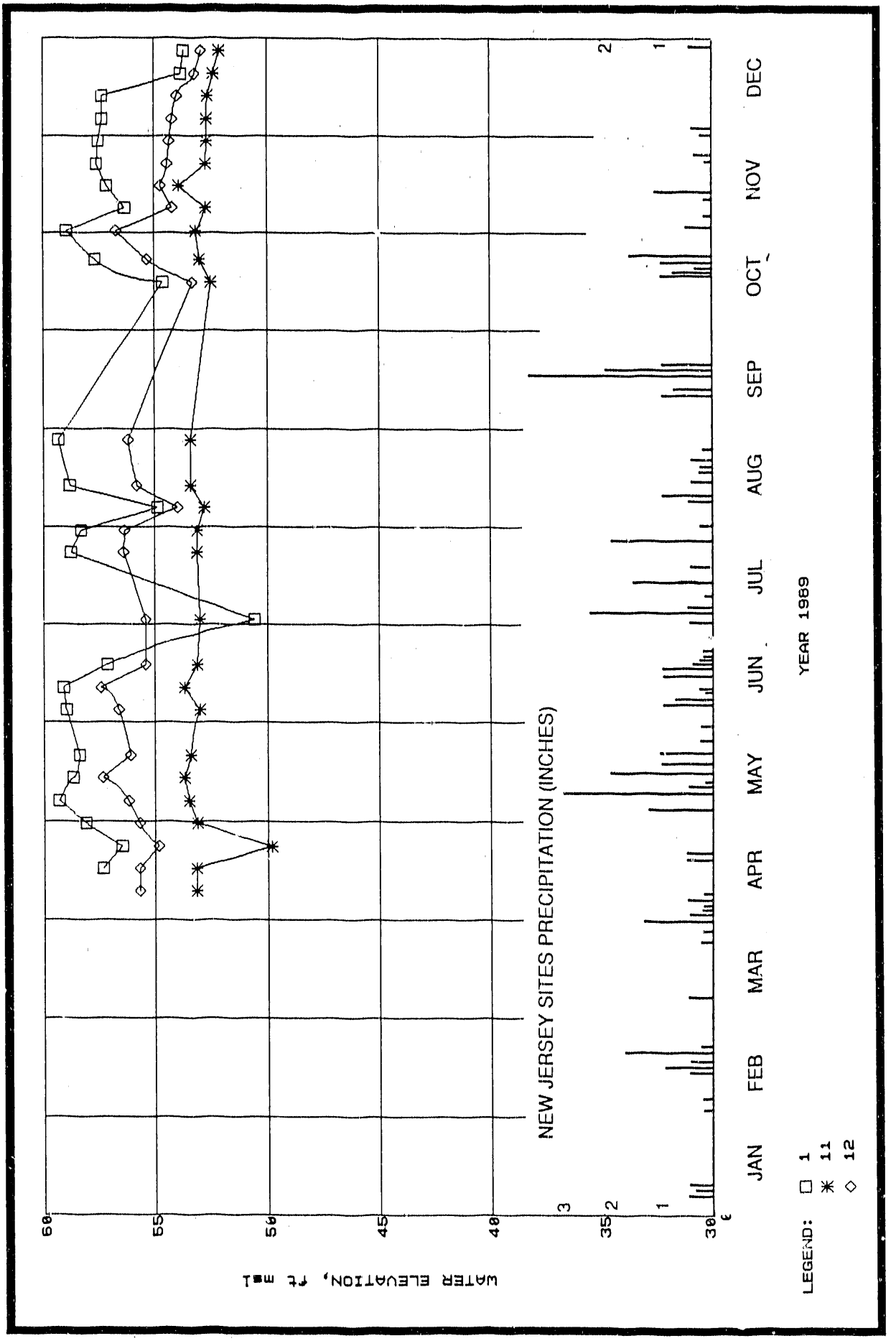

FIGURE 1-7 HYDRCGRAPHS OF UPPER GROUNDWATER SYSTEM WELLS 1, 11, AND 12

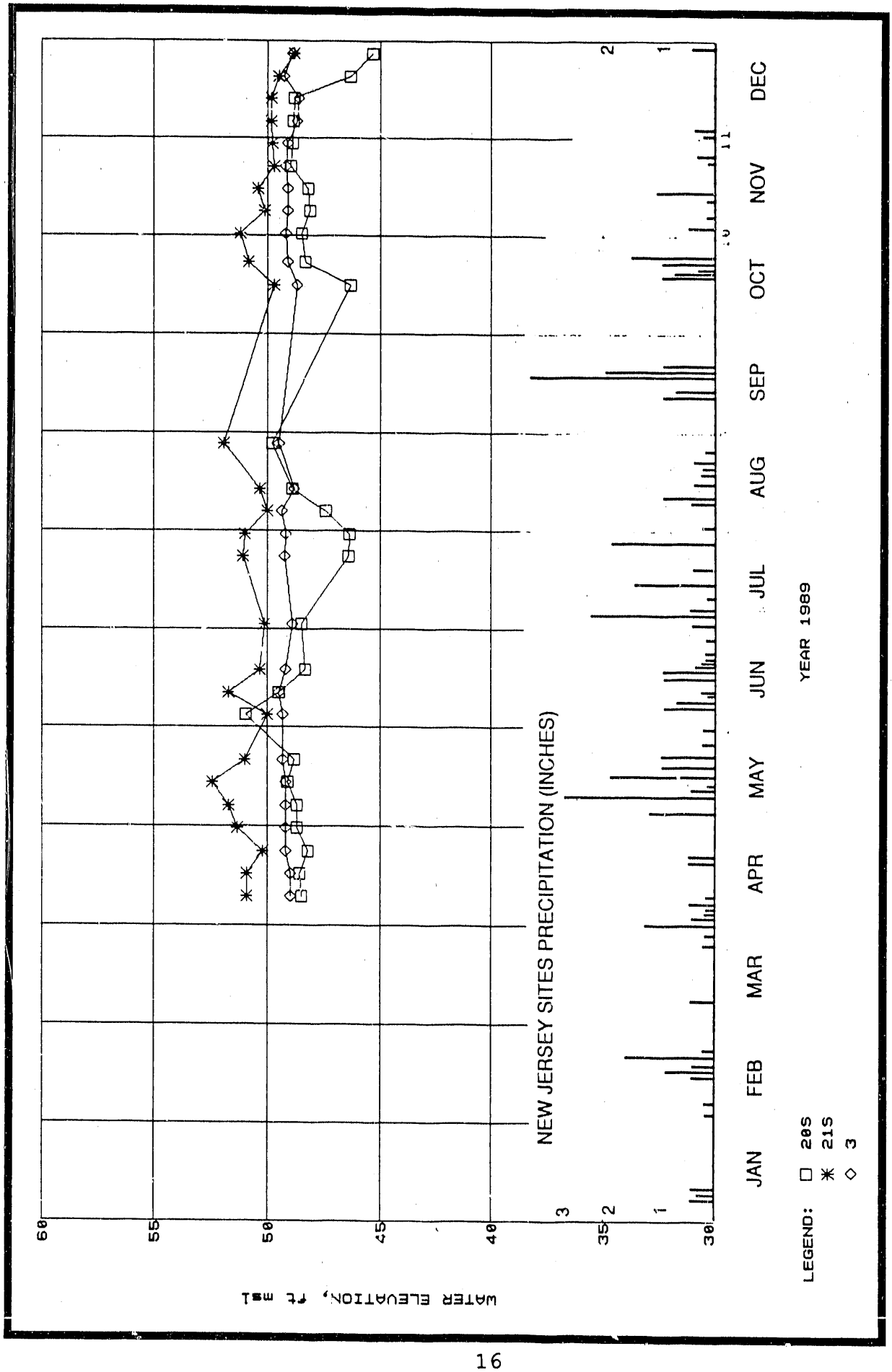

FIGURE 1-8 HYDROGRAPHS OF UPPER GROUNDWATER SYSTEM WELLS 20S, 21S, AND 3

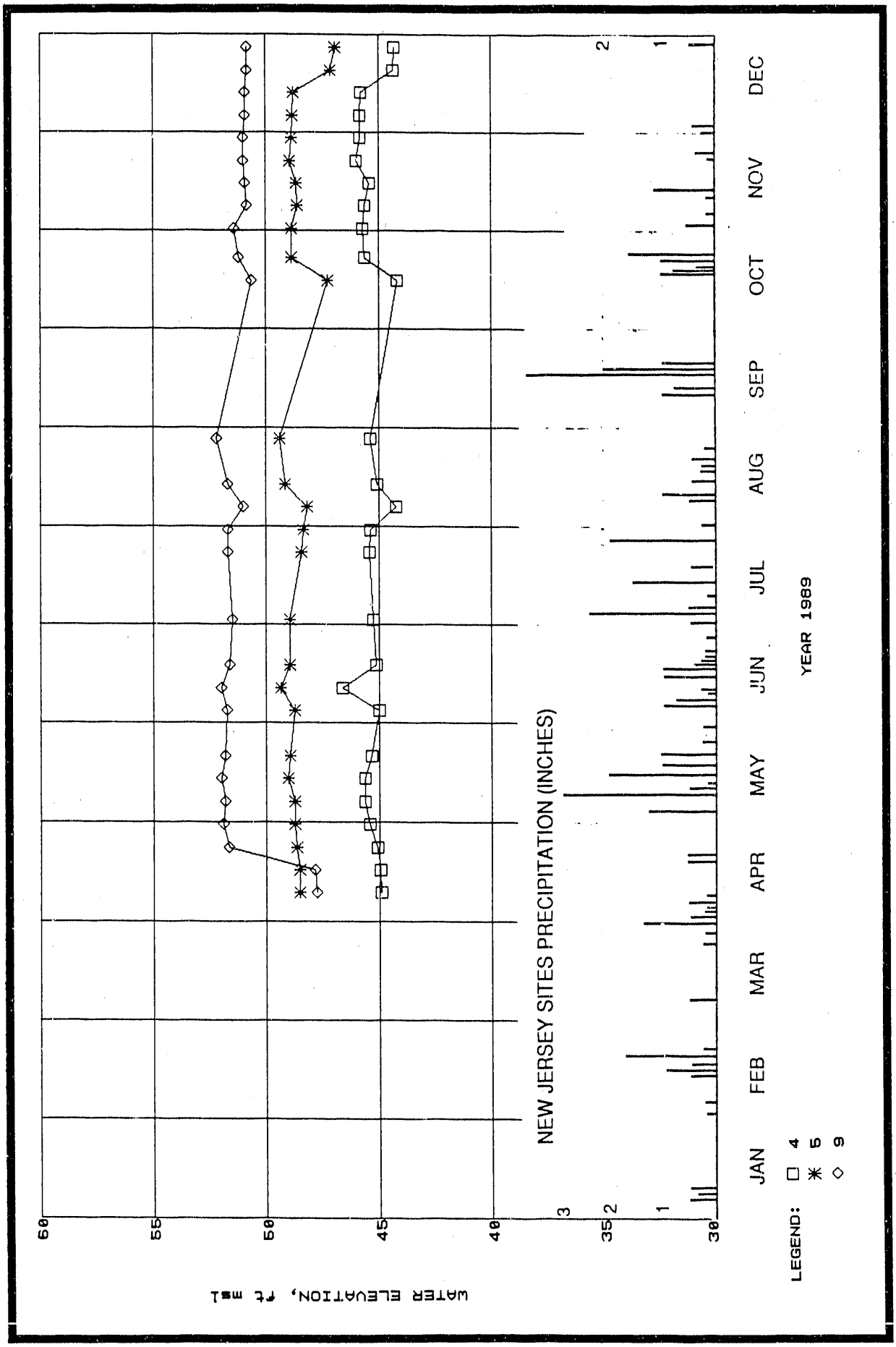

FIGURE 1-9 HYDROGRAPHS OF UPPER GROUNDWATER SYSTEM WELLS 4, 5, AND 9

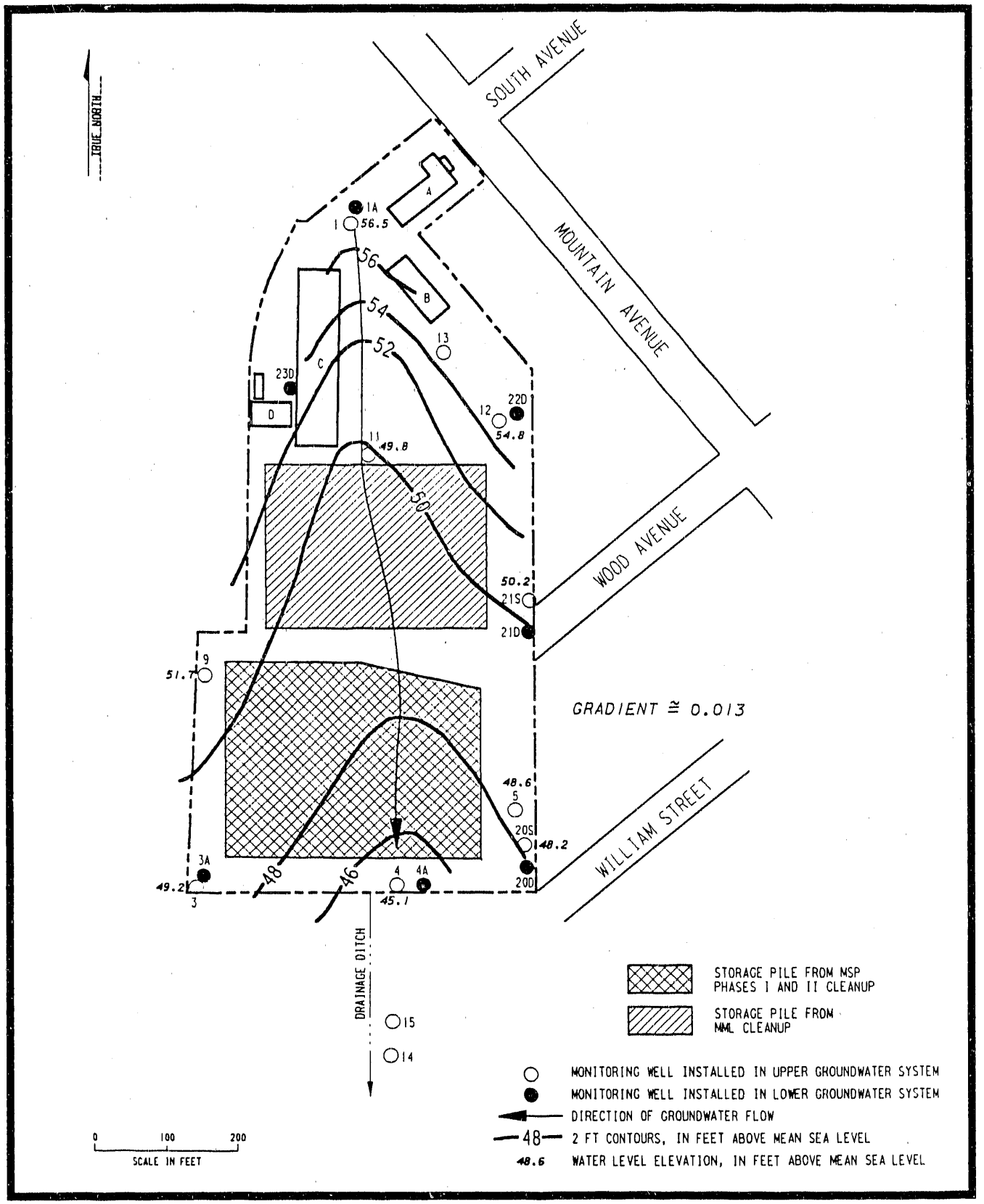

FIGURE 1-10 MSP UPPER GROUNDWATER SYSTEM POTENTIOMETRIC SURFACE (4/24/89)

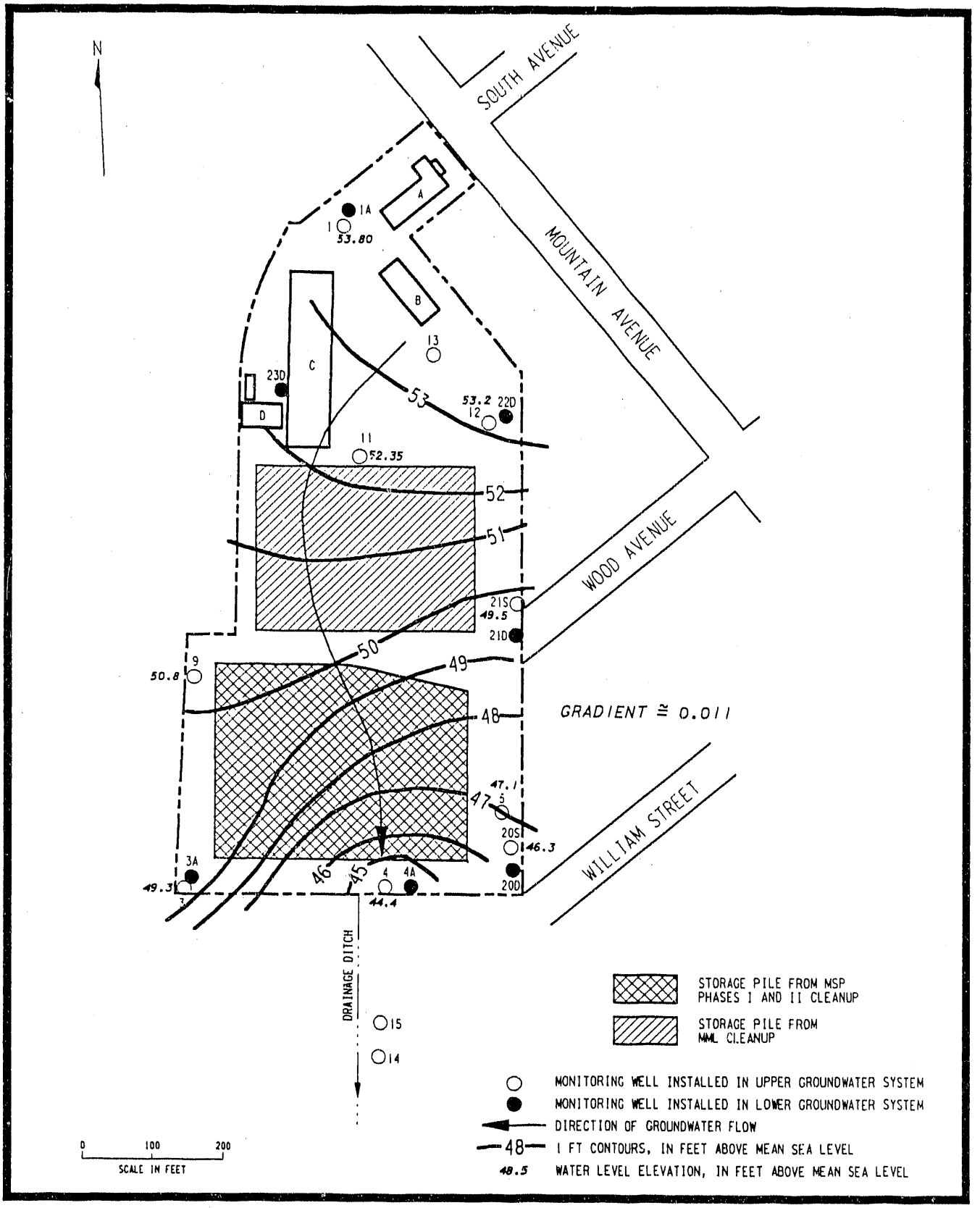

FIGURE 1-11 MSP UPPER GROUNDWATER SYSTEM POTENTIOMETRIC SURFACE (12/20/89)

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water in the Brunswick formation in the interval from 4.6 to 15.3 m (15 to 50 ft) below the ground surface. Wells 1A, 3A, and 4A are open holes, and wells 20D, 21D, 22D, and 23D are screened with PVC. Groundwater level measurements taken in 1989 for each deep well are shown as hydrographs in Figure 1-12. Wells 22D and 23D were accidentally omitted from the water level measuring program in 1989. The precipitation records for the site are shown beneath the hydrographs.

As with the shallow groundwater system, the lower system does not display any apparent seasonal fluctuation in 1989, and correlation of groundwater levels with precipitation events is poor. Slope and flow direction for the lower groundwater system were calculated from two potentiometric surface maps (Figure 1-13 for April and Figure 1-14 for December). As with the upper groundwater system, the groundwater gradient is on the order of 0.01, but the flow is in the opposite direction (from south to northeast).

1.3.3 Conclusions

Conditions observed for the upper and lower groundwater systems indicate no change from the slope and flow directions reported in 1988. No indications of seasonal fluctuations were observed for either system.

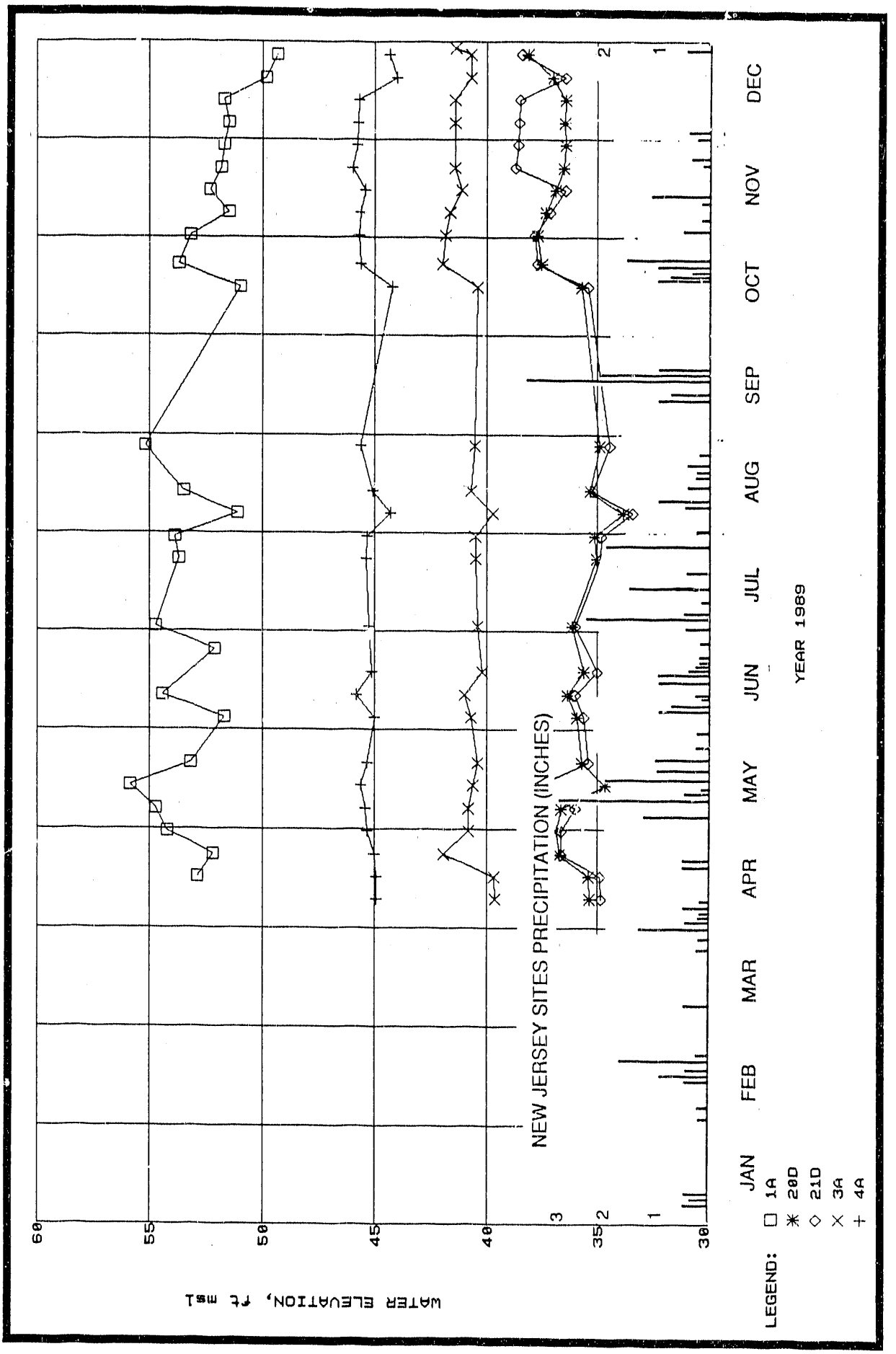

FIGURE 1-12 HYDROGRAPHS OF LOWER GROUNDWATER SYSTEM WELLS 1A, 20D, 21D, 3A, AND 4A

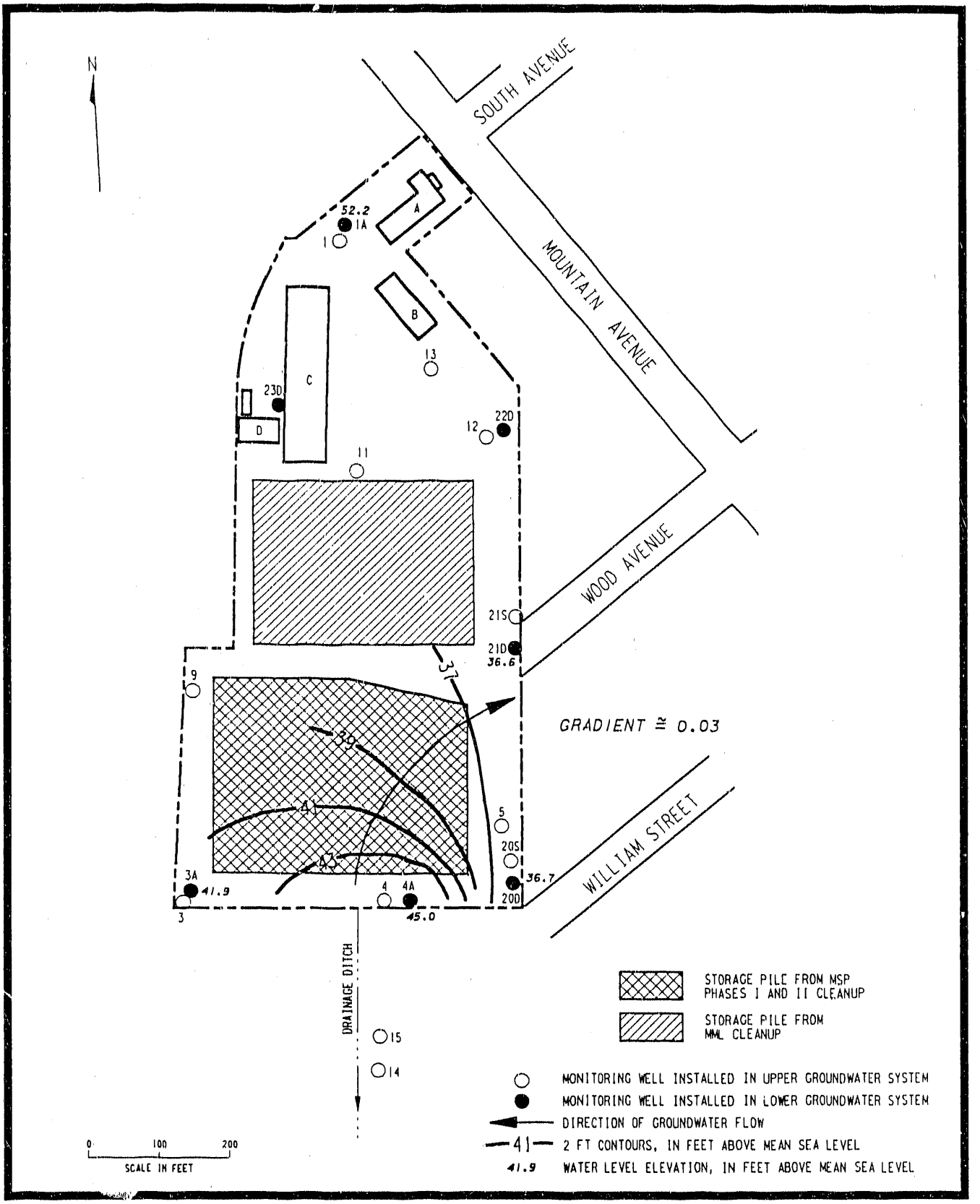

FIGURE 1-13 MSP LOWER GROUNDWATER SYSTEM POTENTIOMETRIC SURFACE (4/24/89)

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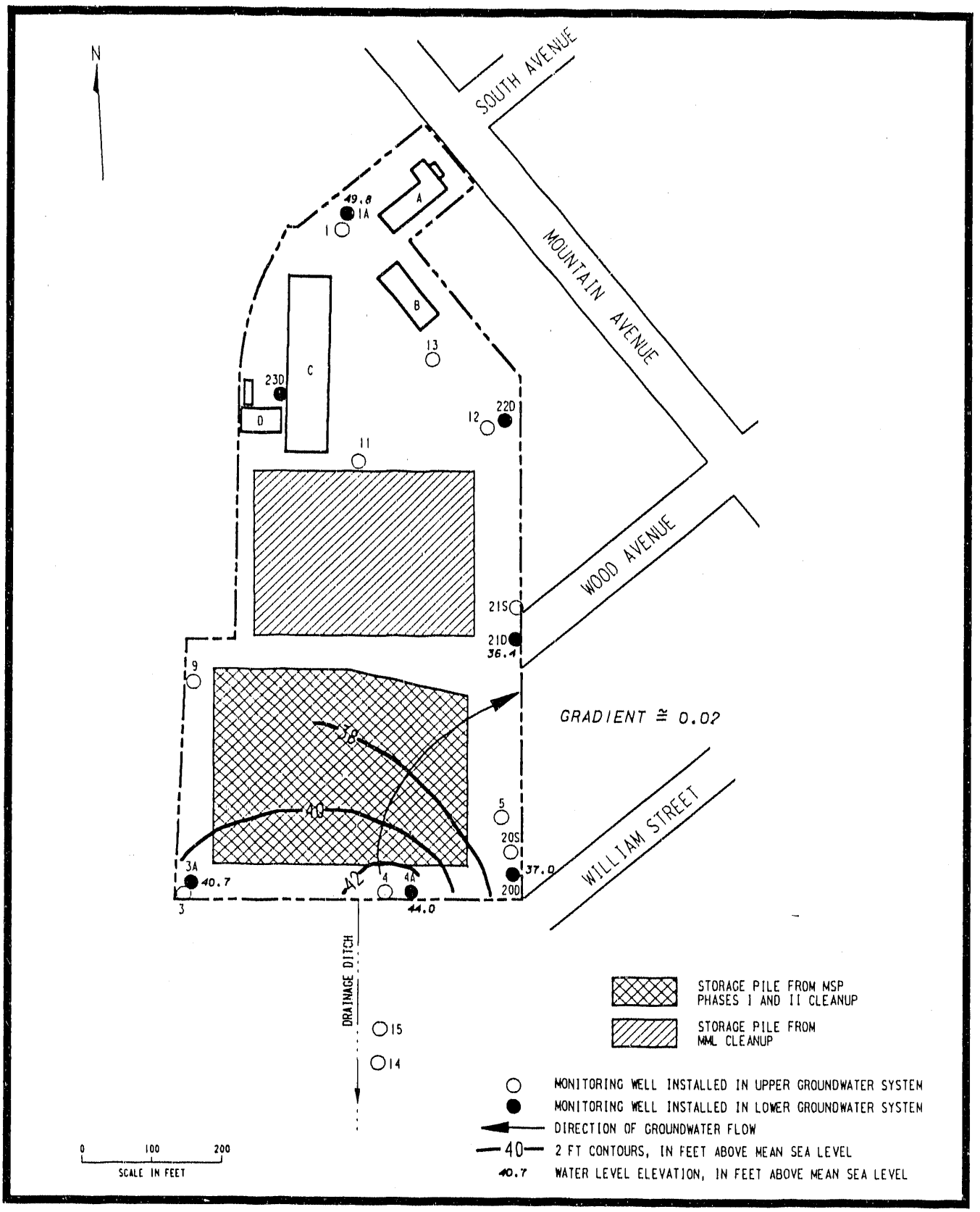

FIGURE 1-14 MSP LOWER GROUNDWATER SYSTEM POTENTIOMETRIC SURFACE (12/20/89)

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2.0 SUMMARY OF MONITORING RESULTS

The environmental monitoring program at MSP continued in 1989; air, water, and sediment samples were taken, and radon and external gamma radiation levels were monitored to verify compliance with the DOE radiation protection standard of 100 mrem/yr (Ref. 15). The potential dose that might be received by a hypothetical maximally exposed individual at the MSP was calculated to determine the degree of compliance with the radiation protection standard.

During 1989, the annual average concentrations of radon (including background) were measured around the perimeter of MSP. Annual average concentrations at MSP ranged from 4×10^{-10} to 1.8×10^{-9} μCi/ml (0.4 to 1.8 pCi/L). Radon concentrations at MSP in 1989 are discussed in Subsection 3.1.

Annual average external radiation levels recorded at the MSP boundary ranged from background to 125 mrem/yr above background. These levels may be compared with the external radiation level from naturally occurring background radiation in the vicinity of MSP, which averaged 76 mrem/yr in 1989. External radiation levels are discussed in Subsection 3.2.

In surface water (Subsection 3.3), the highest annual average concentration of total uranium at the site was 2.2×10^{-8} μCi/ml (22 pCi/L); for radium-226 it was 1.7×10^{-9} μCi/ml (1.7 pCi/L). There have been no definite trends in annual average concentrations of uranium or radium-226 in surface water at MSP (see Subsection 3.7.3).

In groundwater (Subsection 3.4), the highest annual average concentration of total uranium, measured in an on-site well at MSP, was 1.31×10^{-7} μCi/ml (131 pCi/L). For radium-226, the maximum annual average concentration was 7.0×10^{-9} μCi/ml (7.0 pCi/L). Concentrations of radionuclides in surface water and groundwater are within DOE derived concentration guidelines. Chemical analyses of groundwater detected a total of seven pollutants. There is no evidence that MSP is adversely affecting surrounding aquifers.

In stream sediments, the highest annual average concentration of total uranium at the site was 31.8 pCi/g. The highest annual average concentration of radium-226 was 15.2 pCi/g. These concentrations may be compared with the levels of radioactivity in phosphate fertilizers listed in Appendix D.

Calculations were made of the radiological dose received by a hypothetical maximally exposed individual (Subsection 3.6.1). This individual is one who is assumed to be adjacent to the site and who, when all potential routes of exposure are considered, receives the greatest dose. Exposure to external gamma radiation was the exposure pathway quantified because it is the only one that is plausible. The calculated exposure to this hypothetical maximally exposed resident individual at the MSP from this pathway was 2.3 mrem/yr above background. This exposure is approximately equivalent to 2.3 percent of the DOE radiation protection standard.

The cumulative dose to the population within an 80-km (50-mi) radius of the site that results from radioactive materials present at MSP is indistinguishable from the dose that the same population receives from naturally occurring radioactive sources.

Results of the 1989 monitoring show that MSP is in compliance with the DOE radiation protection standard of 100 mrem/yr.

3.0 DATA COLLECTION, ANALYSIS, AND EVALUATION

This section provides the results of 1989 environmental monitoring at MSP. It also describes the sampling, monitoring, and analytical procedures used. Calculations were made to determine the estimated maximum possible radiation dose based on environmental conditions, measurements recorded, and evaluation of potential exposure pathways.

Data are presented in summary tables that include number of data points collected, and minimum, maximum, and average values. Individual sources of error (e.g., analytical error or sampling error) were not estimated. The "less than" notation (<) is used to denote specific sample analysis results that are below the limit of sensitivity of the analytical method, based on a statistical analysis of parameters. When computing annual averages, quarterly values reported as less than a given limit of sensitivity (detection limit) are considered equal to that limit of sensitivity. In previous environmental monitoring reports, when two or more such values were involved in calculating an annual average, the reported value carried the "less than" notation. This year, because limits of sensitivity varied from quarter to quarter, an increasing number of results are at or below the limit of sensitivity, and because data error terms are not reported, a more conservative method of computing annual averages is being employed. Annual averages carry the "less than" notation only if all of the quarterly values involved in the calculation were less than the limit of sensitivity.

Trend tables are provided for radon and external gamma radiation levels and for radionuclides measured in surface water and groundwater. These tables list annual averages for each monitoring location for 1985 through 1989 to allow for comparisons of data and identification of trends in monitoring results (see Subsection 3.7).

3.1 RADON MONITORING

Radon detectors were maintained at 20 locations at MSP (Figure 3-1). Sampling locations were selected on the basis of the potential for elevated radon releases. Detectors are spaced along the site boundary or area of contamination to ensure adequate detection capability under most atmospheric conditions.

The radon data reported for MSP are from 17 monitors around the storage piles and along the site boundary. Data from monitors located inside buildings or situated centrally on the site are not reported because they are not considered representative of conditions at the site boundary.

To measure background radon levels, two additional detector locations were established. One detector was retained at MML. This location is listed in Table 3-1 as MML 4 and is approximately 0.8 km (0.5 mi) north of MSP. The second detector used to measure background radon levels is sampling location 29, located approximately 16 km (10 mi) south of the site.

Radon concentrations are determined using monitors purchased from the Terradex Corporation. These devices (Terradex Type F Track-Etch) consist of an alpha-sensitive film contained in a small plastic cup covered by a membrane through which radon can diffuse. Radon will diffuse through the membrane (in or out of the cup) when a concentration gradient exists; therefore, it will equilibrate with radon in the outside air. Alpha particles from the radioactive decay of radon and its daughters in the cup create tiny tracks when they collide with the film. When returned to Terradex for processing, the films are placed in a caustic etching solution to enlarge the tracks. Under strong magnification, the tracks can be counted. The number of tracks per unit area (i.e., tracks/mm^2) is related through calibration to the concentration of radon in air. Fresh Track-Etch monitors are obtained from Terradex each quarter. Site personnel place these units in each sampling location and return the exposed monitors to Terradex for analysis.

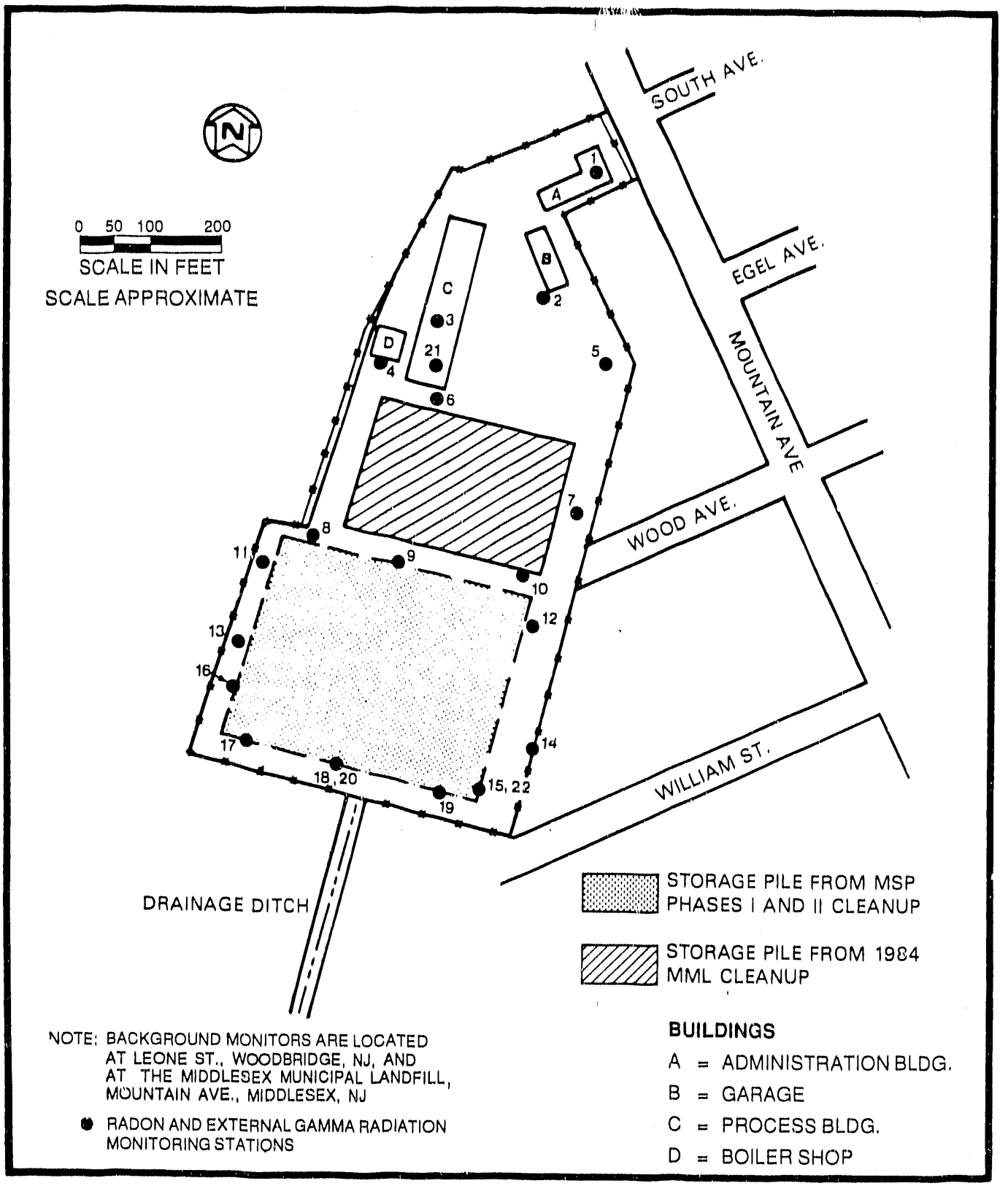

FIGURE 3-1 RADON AND EXTERNAL GAMMA RADIATION MONITORING LOCATIONS AT MSP

Table 3-1 reports the measured concentrations of radon (including background) in air at MSP. Annual average concentrations ranged from 4×10^{-10} to 1.8×10^{-9} μCi/ml (0.4 to 1.8 pCi/L). The annual average background concentration for both background locations was 4×10^{-10} μCi/ml (0.4 pCi/L). Radon levels at MSP are within DOE derived concentration guidelines. For comparisons of the radon concentrations measured from 1985 through 1989, see Subsection 3.7.1.

3.2 EXTERNAL GAMMA RADIATION

External gamma radiation levels were measured at 20 locations at MSP that correspond to the radon (Terradex) detector locations shown in Figure 3-1. Detectors are located around the site boundary to ensure adequate measurement of radiation levels.

External gamma radiation levels are measured using lithium fluoride thermoluminescent dosimeters (TLDs). This system of measurement, used since 1988, utilizes tissue-equivalent dosimeters to provide values that are more realistic in terms of radiation dose to tissues of the body at a depth of 1 cm (0.4 in.). Each dosimetry station contains a minimum of four dosimeters, which are exchanged after approximately one year of accumulated exposure. For example, a dosimeter placed in the station in October 1988 would be removed in October 1989. Each dosimeter contains five individual lithium fluoride chips (each group of five chips is preselected on the basis of having a reproducibility of ± 3 percent across a series of laboratory exposures), the responses of which are averaged. Analysis is performed by Thermo Analytical/Eberline (TMA/E). The average value is then corrected for the shielding effect of the shelter housing (approximately 8 percent). The corrected value is then converted to millirem per year by dividing by the number of days of exposure and subsequently multiplying by 365 days.

Because the current measurement system allows for dosimeter detection interval of approximately a year versus the 3-month interval previously used, the curent system is more sensitive to

TABLE 3-1

RADON-222 CONCENTRATIONS MEASURED AT MSP SITE BOUNDARY, 1989

Sampling Station[a]	Number of Samples	Concentration (10^{-9} µCi/ml)[b,c] Minimum	Maximum	Average
2	4	<0.3	0.5	0.4
4	4	0.8	3.2	1.8
5	4	<0.3	0.7	0.4
7	4	0.3	0.5	0.4
8	4	0.3	0.5	0.4
10	4	0.3	<0.5	0.4
11	4	<0.4	0.6	0.4
12	4	<0.3	0.4	0.4
13	4	<0.3	0.4	0.4
14	4	0.3	0.4	0.4
15	4	<0.4	1.1	0.6
16	4	<0.3	0.9	0.5
17	4	<0.3	0.7	0.5
18	4	<0.3	0.5	0.4
19[d]	4	<0.3	1.0	0.6
20[d]	4	<0.3	0.7	0.5
22[d]	4	<0.3	<0.4	0.4
Background				
29[e]	4	<0.3	0.5	0.4
MML 4[f]	4	<0.3	0.6	0.4

[a]Locations of sampling stations are shown in Figure 3-1. Stations 1, 3, and 21 are inside buildings; stations 6 and 9 are centrally located on the site and are not reported because they are not considered representative of radon concentrations at the site boundary.

[b]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

[c]The measurements are total radon concentrations; background has not been subtracted because of the variability in the distribution of radon.

[d]Stations 20 and 22 are quality controls for stations 18 and 15, respectively.

[e]Located at Leone St., Woodbridge, NJ, approximately 16 km (10 mi) south of MSP.

[f]Located at the Middlesex Municipal Landfill, Mountain Ave., Middlesex, NJ, 0.8 km (0.5 mi) north of MSP.

low radiation levels. Although the tissue-equivalent TLDs used are "state-of-the-art," one should keep in mind when examining the external gamma radiation results that the dosimeter accuracy is approximately ±10 percent at levels from 100 mrem/yr to 1 rem/yr and ±25 percent at radiation levels around 70 mrem/yr.

The results of external gamma radiation monitoring are presented in Table 3-2. For each quarter, an average of the background levels measured was subtracted from the site boundary measurements to provide an estimate of radiation levels resulting from residual materials at the site. Because data from background location MML 4 were incomplete, they were not used in these calculations. The highest annual average gamma radiation level of 125 mrem/yr was measured at station 11 (see Figure 3-1).

The background external gamma radiation value for a given location is not constant. Because the background value is a combination of both natural terrestrial sources and cosmic radiation sources, factors such as the location of the detector in relation to surface rock outcrops, stone or concrete structures, or highly mineralized soil can affect the value measured. Independent of the placement of the detector at the site are the factors of site altitude, annual barometric pressure cycles, and the occurrence and frequency of solar flare activity (Ref. 16).

Because of these factors, the radiation level is not constant from one location to another even over a short time. Thus it is not abnormal for some stations at the boundary of a site to have an external gamma radiation value less than the background level measured some distance from the site.

For comparisons of external radiation levels measured from 1985 through 1989, see Subsection 3.7.2.

3.3 SURFACE WATER SAMPLING

During 1989, sampling was performed to determine the concentrations of total uranium and radium-226 in surface water in the MSP vicinity.

TABLE 3-2

EXTERNAL GAMMA RADIATION LEVELS AT MSP, 1989

Sampling Station[a]	Number of Measurements	Radiation Level (mrem/yr)[b] Minimum	Maximum	Average[c]
2	4	75	94	86
4	4	-[d]	33	20
5	4	41	71	55
7	4	-[d]	24	14
8	4	38	58	48
10	4	50	78	66
11	4	112	140	125
12	4	65	103	90
13	4	33	59	51
14	4	-[d]	22	16
15	4	22	46	35
16	4	14	49	36
17	4	-[d]	28	20
18	4	-[d]	25	15
19	4	13	46	30
20[e]	4	-[d]	-[d]	-[d]
22[e]	3[f]	39	133	54
Background				
29[g]	4	59	101	76
MML 4[h]	1[i]	58	58	58[j]

[a]Locations of sampling stations for MSP are shown in Figure 3-1. Stations 1, 3, and 21 are inside buildings; stations 6 and 9 are centrally located on the MSP site and are not reported because they are not considered representative of dose rates at the site boundary.

[b]Measured background at station 29 has been subtracted from readings at MSP locations.

[c]Average is calculated from the actual number of measurements collected.

[d]Measurement was less than or equal to measured average background value.

[e]Stations 20 and 22 are quality controls for stations 18 and 15, respectively.

[f]TLD recovery error in the second quarter.

[g]Located at Leone St., Woodbridge, NJ, approximately 16 km (10 mi) south of MSP.

[h]Located at the Middlesex Municipal Landfill, Middlesex, NJ, 0.8 km (0.5 mi) north of MSP. Established in April 1988.

[i]No data were available for first quarter because the equipment had been in service for less than a year; no data were available for second and fourth quarters because of sampling errors.

[j]This background reading was not used in calculating the radiation levels.

Surface water samples were collected quarterly at five locations (Figure 3-2). Sampling locations were established on the basis of potential contaminant migration and discharge routes from the site. Sampling points were established both upstream, to establish background conditions; and downstream, to determine the effect of runoff from the sites on surface waters in the vicinity.

Nominal 1.0-L (0.26-gal) grab samples were collected to fill a 3.8-L (1-gal) container and analyzed by TMA/E. The concentration of total uranium was determined by a fluorometric method. Radium-226 concentrations were determined by radon emanation. (This method consists of precipitating radium as sulfate and transferring the sulfate to a radon bubbler, where the radon-222 daughter is allowed to come to equilibrium with its radium-226 parent. The radon-222 is then withdrawn into a scintillation cell and counted by the gross alpha technique. The quantity of radon-222 detected in this manner is directly proportional to the quantity of radium-226 originally present in the sample.)

The results of analyses for total uranium and radium-226 in surface water are presented in Table 3-3. In the vicinity of MSP, annual average total uranium concentrations ranged from $<3 \times 10^{-9}$ to 3.4×10^{-8} μCi/ml (<3 to 34 pCi/L). Average radium-226 levels ranged from 6×10^{-10} to 1.7×10^{-9} μCi/ml (0.6 to 1.7 pCi/L). The highest annual average concentrations of both uranium and radium-226 occurred at the MSP outfall (location 1). All levels measured are well within DOE derived concentration guidelines. For comparisons of radionuclide concentrations measured in surface water from 1985 through 1989, see Subsection 3.7.3.

3.4 GROUNDWATER SAMPLING

During 1989, groundwater samples were collected quarterly from 19 wells at MSP (Figure 1-6). Wells designated 1, 3, 4, 5, 9, 11, 12, 13, 14, 15, 20S, and 21S are installed in the upper groundwater system [approximately 3 m (10 ft) deep]. Groundwater flows from north to south in the upper system; therefore, well 1 is upgradient of the site. Wells 1A, 3A, 4A, 20D, 21D, 22D, and 23D extend into

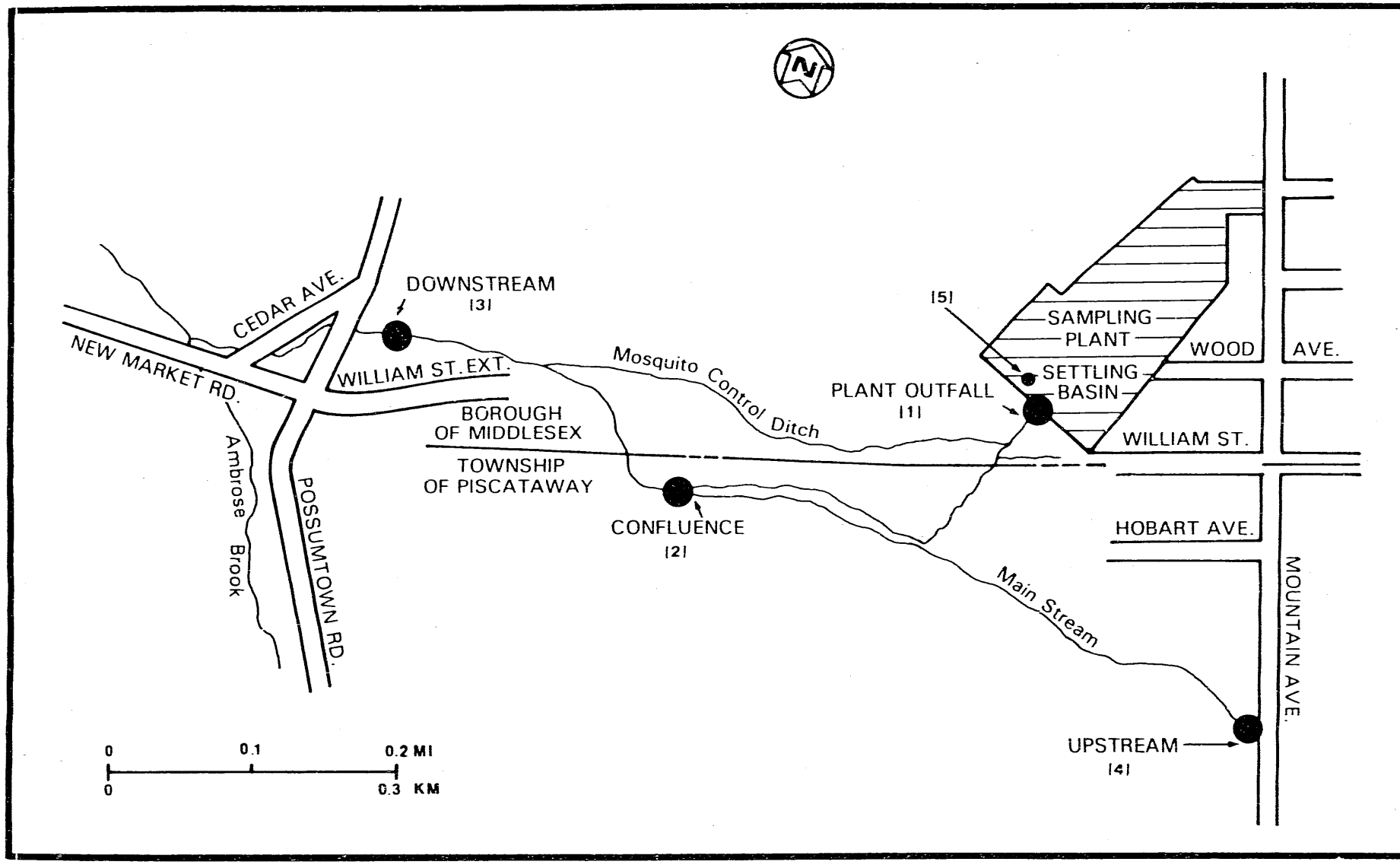

FIGURE 3-2 SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS IN THE VICINITY OF MSP

TABLE 3-3

CONCENTRATIONS OF URANIUM AND RADIUM-226 IN SURFACE WATER IN THE VICINITY OF MSP, 1989

Sampling Location[a]		Number of Samples	Concentration (10^{-9} µCi/ml)[b,c] Minimum	Maximum	Average
Uranium					
1	Plant outfall	4	<3	54	34
2	Confluence	4	<3	<3	<3
3	Downstream (or Main Stream)	4	<3	10	5
4	Upstream[d]	4	<3	<3	<3
5	Settling basin	4	<3	<3	<3
Radium-226					
1	Plant outfall	4	0.8	2.2	1.7
2	Confluence	4	0.3	1.4	0.6
3	Downstream (or Main Stream)	4	0.4	1.0	0.6
4	Upstream[d]	4	0.3	2.8	1.0
5	Settling basin	4	0.5	1.1	0.7

[a]Sampling locations are shown in Figure 3-2.

[b]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

[c]Background has not been subtracted from any values.

[d]Background monitoring location.

the Brunswick formation bedrock aquifer [approximately 15 m (50 ft) deep], which represents the lower groundwater system. Groundwater flows from the south to the northeast in the lower groundwater system; therefore, wells 3A and 4A are the upgradient wells for this system.

Sampling locations were established on the basis of available hydrogeological data and the locations of radioactive materials. Wells are either individual or paired; pairing permits sampling of both the upper and lower groundwater systems at the same location. Nominal 1.0-L (0.26-gal) grab samples were collected to fill a 3.8-L (1-gal) container after the wells had been bailed dry or three casing volumes had been removed and ample recharge time had elapsed. Samples were analyzed by TMA/E for dissolved radium-226 by the methods applied to surface water analyses. The analytical method used to determine total uranium concentration in groundwater was changed from fluorometric analysis to alpha spectrometry in 1986 as required by the New Jersey Department of Environmental Protection (NJDEP). As an analytical method, alpha spectrometry is more precise than the fluorometric method and has the additional advantage that it provides information about the individual isotopes as well as total uranium. Chemical analyses were performed by Weston Analytical Laboratory.

3.4.1 Radiological

Analytical results for uranium are reported in Table 3-4, and radium-226 concentrations are reported in Table 3-5. The highest annual average uranium concentration, 1.31×10^{-7} μCi/ml (131 pCi/L), was measured in well 5, which is located on the southeastern boundary of the site. The maximum uranium concentration of 2.13×10^{-7} μCi/ml (213 pCi/L) was measured in April 1989. Well 20S and well 5 are both shallow wells [approximately 3.05 m (10.0 ft)] that monitor the upper groundwater system and are very close to each other (Figure 1-6). The average uranium value of 2×10^{-9} μCi/ml (2 pCi/L) for well 20S, compared with the much higher average value of 1.31×10^{-7} μCi/ml

TABLE 3-4

CONCENTRATIONS OF URANIUM IN GROUNDWATER AT MSP, 1989

Sampling Location[a]	Number of Samples	Concentration (10^{-9} µCi/ml)[b] Minimum	Maximum	Average
1	4	<3	8	4
1A	4	5	15	9
3	4	2	4	3
3A	4	5	6	5
4	3[c]	5	7	6
4A	4	14	25	17
5	3[c]	80	213	131
9	4	2	7	4
11	4	22	79	42
12	4	3	12	7
13	4	<3	<3	<3
14	1[d]	<3	<3	<3
15	4	<3	5	4
20D	4	2	3	2
20S	4	1	2	2
21D	4	2	5	3
21S	4	1	2	1
22D	4	<3	<3	<3
23D	4	<3	<3	<3
Background				
MML 17[e]	3[c]	<3	5	4

[a]Sampling locations are shown in Figure 1-6. "A" and "D" designate wells installed in the lower groundwater system; "S" designates wells installed in the upper system.

[b]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

[c]Well was dry in the first quarter.

[d]Well was dry in the first three quarters.

[e]Located at the Middlesex Municipal Landfill, Middlesex, NJ, 0.8 km (0.5 mi) north of MSP. This well was reinstated in the monitoring program in October 1988 to represent background. Background has not been subtracted from other well measurements.

TABLE 3-5

CONCENTRATIONS OF RADIUM-226 IN GROUNDWATER AT MSP, 1989

Sampling Location[a]	Number of Samples	Concentration (10^{-9} µCi/ml)[b] Minimum	Maximum	Average
1	4	0.7	1.0	0.9
1A	4	0.5	0.9	0.7
3	4	1.1	2.0	1.6
3A	4	0.8	1.2	1.0
4	3[c]	1.7	2.4	2.1
4A	4	0.6	1.2	0.9
5	3[c]	2.3	2.6	2.4
9	4	2.5	13.5	7.0
11	4	2.9	7.3	4.7
12	4	1.0	3.3	2.2
13	4	0.3	0.9	0.7
14	1[d]	1.0	1.0	1.0
15	4	0.5	0.9	0.8
20D	4	<0.5	1.0	0.8
20S	4	0.3	1.1	0.7
21D	4	0.4	0.9	0.7
21S	4	0.6	1.2	0.9
22D	4	0.4	1.2	0.7
23D	4	0.4	0.8	0.6
Background				
MML 17[e]	3[c]	0.5	0.8	0.7

[a]Sampling locations are shown in Figure 1-6.

[b]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

[c]Well was dry in the first quarter.

[d]Well was dry in the first three quarters.

[e]Located at the Middlesex Municipal Landfill, Middlesex, NJ, 0.8 km (0.5 mi) north of MSP. This well was reinstated in the monitoring program in October 1988 to represent background. Background has not been subtracted from other well measurements.

(131 pCi/L) for well 5, indicates that well 5 is located adjacent to or within an area of contaminated material.

The elevated uranium level in well 5 was enhanced by reduced precipitation during the early part of 1989, which decreased the volume of infiltration; thus water collected from well 5 had increased concentrations of dissolved solids from the waste material. Purging the well during the sampling cycle increased the local hydraulic gradient and introduced additional suspended solids from the adjacent waste materials. The slow recovery time after purging allowed further accumulation of the solids and therefore increased uranium concentrations in samples taken from this well. Water in this well is not available for human consumption. The highest annual average concentration of radium-226 was 7.0×10^{-9} μCi/ml (7.0 pCi/L). All uranium and radium-226 concentrations measured in 1989 groundwater samples were within DOE derived concentration guidelines.

3.4.2 Chemical

As required by a New Jersey Pollutant Discharge Elimination System permit, groundwater samples from MSP wells were analyzed quarterly for pH, total organic carbon (TOC), total organic halides (TOX), and specific conductance. Analyses are performed annually for the New Jersey priority pollutants. Table 3-6 lists analytical results for indicator parameters and chemical contaminants that were detected. Numerous other chemical contaminants for which analyses were completed were not detected in any groundwater sample (see Table 3-7).

Specific conductance and pH measure changes in the inorganic composition of the groundwater. Acidity or basicity of water is expressed as pH. A change in pH affects the solubility and mobility of chemical contaminants in groundwater. Specific conductance measures the capacity of water to conduct an electrical current. Generally, conductivity increases with an elevated concentration of dissolved solids. Waters with high salinities or high total dissolved solids exhibit high conductivities.

TABLE 3-6

INDICATOR PARAMETERS AND CHEMICAL CONTAMINANTS DETECTED IN GROUNDWATER AT MSP, 1989[a]

Parameter (unit)	Analysis Results by Sampling Location (Monitoring Well Number)											
	3	3A[b]	4	4A[b]	5	9	11	12	20D	20S	21D	21S
pH (standard units)	7.3-7.4	7.2-7.4	6.0-6.3	5.9-6.9	5.7-6.4	6.6-7.1	7.1-7.2	6.3-7.4	7.7-8.0	5.7-6.1	7.6-7.9	6.0-6.3
Total organic carbon (mg/L)	8.8-15.5	6.9-11.2	1.9-5.0	2.2-4.2	2.3-3.2	18.5-131.0	0.86-23.9	2.7-8.3	0.75-4.6	2.4-7.5	0.55-2.0	2.8-4.7
Total organic halides (µg/L)	ND-36	20-32	ND-40	ND-31	ND-56	ND-48	ND	ND-24	ND-14	ND-32	24-79	ND-45
Specific conductance (µmhos/cm)	472-495	534-592	164-235	207-294	158-210	435-712	74.2-166	72.1-209	294-368	179-195	315-386	151-184
Benzene (µg/L)	ND	ND	ND	ND	ND	7	ND	ND	ND	ND	ND	ND
Acetone (µg/L)	ND	ND	ND	42	410	110	ND	ND	ND	ND	25	ND
Trichloroethylene (µg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	53	ND
Toluene (µg/L)	ND	ND	ND	ND	ND	25	ND	ND	ND	ND	ND	ND
Xylene (µg/L)	ND	ND	ND	ND	ND	12	ND	ND	ND	ND	ND	ND
Bis(2-ethylhexyl)phthalate (µg/L)	70	50	50	11	16	29	23	21	16	98	ND	19
Methylene chloride (µg/L)	ND	5	5	5	ND	5	ND	7	5	5	5	5

[a] Does not include parameters for which concentrations were below the limit of sensitivity of the analytical method used.

[b] Upgradient background well for lower groundwater system.

ND - no detectable concentration.

TABLE 3-7

CHEMICAL CONTAMINANTS NOT DETECTED IN GROUNDWATER AT MSP, 1989

Acrolein	Bis(2-chloroethoxy)methane	Phenanthrene
Acrylonitrile	Bis(2-Chloroisopropyl)ether	Pyrene
Bromoform	4-bromophenyl phenyl ether	2-chlorophenol
Carbon tetrachloride	Butylbenzyl phthalate	2,4-dichlorophenol
Chlorobenzene	2-chloronaphthalene	2,4-dimethylphenol
Chlorodibromomethane	4-chlorophenyl phenyl ether	2,4-dinitrophenol
Chloroethane	4-chloroaniline	2-nitrophenol
Chloroform	4-chloro-3-methylphenol	4-nitrophenol
2-chloroethyl vinyl ether	Chrysene	Pentachlorophenol
Dichlorobromomethane	Dibenzo(a,h)anthracene	Phenol
1,3-dichloropropylene	Dibenzofuran	2,4,5-trichlorophenol
1,2-trans-dichloroethylene	Di-n-butyl phthalate	2,4,6-trichlorophenol
1,1-dichloroethane	Di-n-octyl phthalate	Aldrin
1,2-dichloroethane	1,2-dichlorobenzene	BHC, alpha
1,1-dichloroethylene	1,3-dichlorobenzene	BHC, beta
1,2-dichloropropane	1,4-dichlorobenzene	BHC, gamma
1,3-dichloropropene	3,3'-dichlorobenzidine	BHC, delta
Ethylbenzene	Diethyl phthalate	Alpha chlordane
Methyl bromide	Dimethyl phthalate	Beta chlordane
Methyl chloride	2,4-dinitrotoluene	Dieldrin
Styrene	2,6-dinitrotoluene	Endosulfan I
1,1,2,2-tetrachloroethane	4,6-dinitro-2-methylphenol	Endosulfan II
1,1,1-trichloroethane	Fluoranthene	Endosulfan sulfate
Trichlorofluoromethane	Fluorene	Endrin
1,1,2-trichloroethane	Hexachlorobenzene	Endrin ketone
Tetrachloroethylene	Hexachlorobutadiene	Heptachlor
Vinyl chloride	Hexachloroethane	Heptachlor epoxide
Anthracene	Hexachlorocyclopentadiene	4,4'-DDT
Acenaphthene	Indeno(1,2,3-cd)pyrene	4,4'-DDE
Acenaphthylene	Isophorone	4,4'-DDD
Benzo(a)anthracene	2-methylnapthalene	Methoxychlor
Benzo(k)fluoranthene	2-methylphenol	Aroclor 1016
Benzo(a)pyrene	4-methylphenol	Aroclor 1221
Benzo(g,h,i)perylene	Naphthalene	Aroclor 1232
Benzyl alcohol	Nitrobenzene	Aroclor 1242
Benzoic acid	2-nitroaniline	Aroclor 1248
Bis(2-chloroethyl)ether	3-nitroaniline	Aroclor 1254
	4-nitroaniline	Aroclor 1260
	N-nitrosodi-n-propylamine	Toxaphene
	N-nitrosodiphenylamine	

Groundwater is analyzed for TOC and TOX to determine organic content. TOC measures the total organic carbon content of water but is not specific to a given contaminant. TOX measures organic compounds containing halogens; many pollutants contain halogenated hydrocarbons, which are organic compounds containing fluorine, chlorine, bromine, and iodine.

Specific conductivity and pH measurements ranged from 72.1 to 592 μmhos/cm and 5.7 to 8.0, respectively. TOX results ranged from below detection limits to 79 μg/L, and TOC results ranged from 0.55 to 131 mg/L. Except for TOC levels in well 9, indicator parameter results for downgradient wells are similar to those for upgradient wells and probably represent background conditions for the area. The elevated TOC level in well 9 reflects the presence of organic pollutants. There is no evidence that these pollutants have migrated.

The appearance of bis(2-ethylhexyl)phthalate is almost certainly a result of laboratory contamination; it appeared in all of the laboratory blanks at concentrations up to 100 μg/L. The laboratory is aware of the problem and is taking steps to correct it.

Although the presence of the detected contaminants would not be expected in pristine groundwater, their occurrence at trace levels is not unusual in groundwater underlying areas developed for industrial purposes.

Measurement of water levels and water quality continues to provide additional information on groundwater gradient and flow directions.

3.5 SEDIMENT SAMPLING

During 1989, sediment samples consisting of composites weighing approximately 500 g (1.1 lb) were collected at the five surface water sampling locations shown in Figure 3-2. The sampling locations correspond with surface water sampling locations.

TMA/E analyzed the samples for uranium and radium-226. The concentration of total uranium was determined by summing the

results of analyses for isotopic uranium. Isotopic uranium concentration was determined by alpha spectrometry, where the uranium is leached, organically extracted, and electroplated on a metal substrate. Radium-226 concentrations were determined by radon emanation (described earlier).

Results of these analyses, based on dry weight, are presented in Table 3-8. Annual average concentrations of uranium and radium-226 in the vicinity of MSP ranged from 2.8 to 31.8 pCi/g and 1.0 to 15.2 pCi/g, respectively. Sampling locations 1, 2, and 3 each yielded one quarterly sample with elevated levels of uranium and radium-226. Although levels of these radionuclides were low at all locations in the fourth quarter of 1989, they will be closely monitored in 1990. An expanded sampling plan for locations 1, 2, and 3 has been scheduled for April 1990 to better determine sediment quality in these areas and to locate the source(s) of the contamination.

3.6 RADIATION DOSE

To assess the health effects of the radioactive materials stored at MSP, radiological exposure pathways were evaluated to calculate the dose to a hypothetical maximally exposed individual. This individual is one who is assumed to be adjacent to the site and who, when all potential routes of exposure are considered, receives the greatest dose. An appraisal of potential pathways (exposure to external gamma radiation, ingestion of water, and inhalation of radon) suggested that external gamma radiation was the only plausibly significant exposure mode.

The dose from ingesting groundwater or surface water from sources on MSP property was not calculated because it was considered unrealistic to assume that ingestion of this water would occur. MSP is fenced and locked, and security is well maintained. Therefore, a member of the public could only consume water on the site by trespassing on the property every day to gain access to the water. To consume groundwater from a well at the site, the member of the public would also have to be equipped with a means of removing the locked well cap and extracting the groundwater.

TABLE 3-8

CONCENTRATIONS OF URANIUM AND RADIUM-226 IN SEDIMENT IN THE VICINITY OF MSP, 1989

Sampling Location[a]		Number of Samples	Concentration [pCi/g (dry)] Minimum	Maximum	Average
Uranium					
1	Plant outfall	3[b]	<1.4	37.7	13.5
2	Confluence	2[b,c]	12.5	51.0	31.8
3	Downstream (or Main Stream)	4	<1.6	41.8	12.6
4	Upstream	4	<1.0	6.4	2.8
5	Settling basin	3[c]	2.5	<4.0	3.4
Radium-226					
1	Plant outfall	3[b]	0.5	18.0	6.4
2	Confluence	2[b,c]	2.3	28.0	15.2
3	Downstream (or Main Stream)	4	0.4	19.0	5.4
4	Upstream	4	0.4	2.5	1.0
5	Settling basin	3[c]	1.7	2.0	1.8

[a]Sampling locations are shown in Figure 3-2.

[b]No sediment present during the third quarter.

[c]Frozen in the first quarter.

Radon concentrations measured at the MSP boundaries were within the normal variation associated with background measurements for this area. Consequently, this pathway would not increase the dose received by the hypothetical maximally exposed individual.

3.6.1 Dose to the Maximally Exposed Individual

To identify the individuals in the vicinity of the MSP who would receive the highest doses from on-site radioactive materials, the dose from exposure to external gamma radiation was calculated at all the monitoring locations that could be accessible to the public. These doses were then reviewed with regard to land use and occupancy factors for areas adjacent to the monitoring points. For the properties surrounding MSP, the highest dose would be receive. to the east of the site in a residential area near location 5 and west of the site at a commercial scrap metal facility near location 11. The dose calculations were based on certain assumptions, described below.

At the scrap metal facility, if an occupancy factor near location 11 of 2 h/week is applied, the dose to the maximally exposed individual would be 1.5 mrem/yr. The annual average dose rate measured at location 5 was 55 mrem/yr. The dose to an individual working in the backyard of the residence nearest this location for 1 h/day, 365 days/yr, would be 2.3 mrem/yr. These exposures are approximately equivalent to the exposure a person receives during one flight from New York City to Los Angeles because of greater amounts of cosmic radiation at higher altitudes (see Appendix D).

These values reflect the assumption that the maximally exposed individual is exposed to the radiation fields present at the locations of the detectors. The individual's exposure rate would actually be much lower because gamma radiation levels decrease rapidly as distance from the source of contamination increases.

3.6.2 Dose to the Population in the Vicinity of MSP

The dose to the population represents the conceptual cumulative radiation dose to all residents within an 80-km (50-mi) radius of a given site. This calculated dose includes contributions from all potential pathways. For MSP these pathways are direct exposure to gamma radiation, inhalation of radon, and ingestion of water containing radioactivity.

The contribution to the population dose made by external gamma radiation from the radioactive materials present on the site is too small to be measured, since gamma radiation levels decrease rapidly as distance from the source of contamination increases. For example, if the gamma exposure rate at a distance of 1 m (3 ft) from a small-area radioactive source were 100 mrem/yr, the exposure rate at a distance of 6.4 m (21 ft) from the source would be indistinguishable from naturally occurring background radiation.

Similarly, radon is known to dissipate rapidly as distance from the radon source increases (Ref. 17). Therefore, exposure from the low radon concentrations at MSP (approximately equal to the natural background level) does not contribute significantly to population dose.

On the basis of radionuclide concentrations measured in water leaving MSP, it also appears that there is no plausible pathway by which ingestion of water could result in a significant dose to the population. As water migrates farther from the source, radionuclide concentrations are further reduced, thereby lowering potential doses to even less significant levels.

Because the contributions to population dose via all three potential exposure pathways are inconsequential, calculation of dose to the population is not warranted. The cumulative dose to the population within an 80-km (50-mi) radius of MSP that would result from radioactive materials present at the site would be indistinguishable from the dose that the same population receives from naturally occurring radioactive sources.

3.7 TRENDS

The environmental monitoring program at MSP was established to allow an annual assessment of the environmental conditions at the site, provide a historical record for comparisons from year to year, and permit detection of trends over time. In the following subsections, 1989 annual averages for each monitoring location for radon, external gamma radiation, surface water, and groundwater are compared with results for 1985-1988 (Refs. 9 through 12).

3.7.1 Radon

Radon concentrations measured at MSP in 1989 are approximately the same as 1988 levels. Table 3-9 shows radon levels at MSP from 1985-1989. When compared with background variations, measured MSP radon concentrations show no notable trends and seem to contribute little, if any, to naturally occurring radon levels in the area.

The behavior of radon and the variables that affect its concentration are difficult to predict. Such factors as moisture content of the soil, disturbance of the soil, barometric pressure, temperature inversions, and hydrogeologic conditions all affect local radon concentrations over both the short term and the long term.

3.7.2 External Gamma Radiation

Comparison of the 1989 external gamma radiation data with data from other years yields no apparent trends (see Table 3-10). Although some locations exhibit higher levels than others, radiation levels from year to year at any given location vary within what are becoming characteristic ranges for those locations.

3.7.3 Surface Water

As shown in Table 3-11, few notable trends have been identified as to the concentrations of uranium and radium-226 in surface water

TABLE 3-9

ANNUAL AVERAGE RADON-222 CONCENTRATIONS MEASURED AT MSP SITE BOUNDARY, 1985-1989[a]

Sampling Station[b]	Concentration (10^{-9} µCi/ml)[c,d] 1985	1986	1987	1988	1989
MSP					
2	0.3	0.6	1.0	0.3	0.4
4	0.5	1.0	0.8	0.7	1.8
5	0.2	0.8	0.8	0.6	0.4
7	0.3	1.0	0.9	0.3	0.4
8	0.3	1.0	0.6	0.3	0.4
10	0.2	1.0	0.7	0.4	0.4
11	0.2	1.1	1.0	0.3	0.4
12	0.3	0.9	0.4	0.5	0.4
13	0.3	0.9	1.4	0.4	0.4
14	0.4	1.2	0.9	0.4	0.4
15	0.3	0.3	0.3	0.4	0.6
16	0.2	0.7	0.8	0.3	0.5
17	0.2	0.7	0.7	0.4	0.5
18	0.2	0.8	1.0	0.6	0.4
19	0.2	1.1	1.3	0.4	0.6
20[e]	0.3	1.1	1.5	0.5	0.5
22[e]	0.4	0.9	1.6	0.3	0.4
Background					
29[f]	0.8	2.0	1.2	0.3	0.4
MML 4[g]	0.3	0.4	0.9	0.4	0.4

[a]Sources of data for prior years are the annual site environmental reports for those years (Refs. 9-12).

[b]Locations of sampling stations are shown in Figure 3-1. MSP locations 1, 3, and 21 are inside buildings; locations 6 and 9 are centrally located on the MSP site and are not reported because they are not considered representative of radon concentrations at the site boundary.

[c]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

[d]The measurements are total radon concentrations. Because of the variability in the distribution of radon, background has not been subtracted.

[e]In 1985, locations 20 and 22 were established as quality control stations for locations 18 and 15, respectively.

[f]Located at Leone St., Woodbridge, NJ, approximately 16 km (10 mi) south of MSP.

[g]Located at the Middlesex Municipal Landfill, Middlesex, NJ, approximately 0.8 km (0.5 mi) north of MSP.

TABLE 3-10

ANNUAL AVERAGE EXTERNAL GAMMA RADIATION LEVELS AT MSP, 1985-1989[a]

Sampling Station[b]	Radiation Level (mrem/yr)[c] 1985	1986	1987	1988	1989
2	129	75	60	112	86
4	57	41	31	48	20
5	111	125	99	115	55
7	49	22	17	25	14
8	67	46	23	63	48
10	101	60	44	115	66
11	167	121	94	155	125
12	80	72	55	142	90
13	78	33	40	61	51
14	48	29	19	32	16
15	41	37	27	50	35
16	59	36	17	34	36
17	49	25	13	31	20
18	42	28	14	21	15
19[d]	41	32	13[e]	28[e]	30
20[d]	1	3	0	0	0[e]
22[d]	60	43	20	48	54
Background					
29[f]	99	71	71	90	76
MML 4[g]	--	--	--	--	58

[a]Sources of data for 1985-1988 are the annual site environmental reports for those years (Refs. 9-12).

[b]Locations of sampling stations are shown in Figure 3-1. Stations 6 and 9 are centrally located on the MSP site and are not reported because they are not considered representative of external gamma radiation levels at the site boundary.

[c]Measured background has been subtracted from readings obtained at MSP sampling locations.

[d]In 1985, stations 20 and 22 were established as quality controls for stations 18 and 15, respectively.

[e]Measurement was less than or equal to the measured background value.

[f]Located at Leone St., Woodbridge, NJ, approximately 16 km (10 mi) south of MSP.

[g]Located at the Middlesex Municipal Landfill, Middlesex, NJ, approximately 0.8 km (0.5 mi) north of MSP. Established April 1988.

TABLE 3-11

ANNUAL AVERAGE CONCENTRATIONS OF URANIUM AND RADIUM-226 IN SURFACE WATER IN THE VICINITY OF MSP, 1985-1989[a]

Sampling Location[b]	Concentration (10^{-9} µCi/ml)[c] 1985	1986	1987	1988	1989
Uranium					
1 Plant outfall	80	56	54	47	22
2 Confluence	10	23	5	3	<3
3 Downstream (or Main Stream)	4	21	<3	4	5
4 Upstream	3	<3	<3	3	16
5 Settling basin	7	<3	<3	4	<3
Radium-226					
1 Plant outfall	3.3	2.2	1.7	2.0	1.7
2 Confluence	0.3	1.0	0.7	0.3	0.6
3 Downstream (or Main Stream)	0.2	1.1	0.6	0.2	0.6
4 Upstream	0.4	0.2	0.6	0.2	1.0
5 Settling basin	0.7	0.5	0.7	0.3	0.7

[a]Data sources for 1985-1988 are the annual site environmental reports for those years (Refs. 9-12).

[b]Sampling locations are shown in Figure 3-2.

[c]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

at MSP. Localized decreases in uranium concentration at the confluence and downstream sampling points are similar to previously measured ranges. Uranium levels at the plant outfall appear to be dropping steadily from a peak in 1984 of 1.03×10^{-7} μCi/ml (103 pCi/L)(Ref. 8) to 2.2×10^{-8} μCi/ml (22 pCi/L) in 1989. The increased 1989 annual average for uranium at location 4 may be due to laboratory error during the first quarter of sampling; the reported value for that quarter was 5.42×10^{-8} μCi/ml (54.2 pCi/L). Subsequent quarterly samples were all measured as having the more typical level of $<3 \times 10^{-9}$ μCi/ml (<3.0 pCi/L).

3.7.4 Groundwater

As shown in Tables 3-12 and 3-13, uranium levels measured in groundwater in 1989 appear to approximate those of previous years. Radium-226 levels appear unchanged. No long-term trends for either uranium or radium-226 can be inferred.

A comparison of upgradient and downgradient conditions at MSP indicates that groundwater quality is not degraded as it crosses the site. Wells 3A and 4A are upgradient and 21D and 22D are downgradient for the lower groundwater system. For the upper system, well 1 is upgradient and wells 3 and 4 are downgradient.

TABLE 3-12

ANNUAL AVERAGE CONCENTRATIONS OF URANIUM IN GROUNDWATER AT MSP, 1985-1989[a]

Sampling Location[b]	Concentration (10^{-9} µCi/ml)[c]				
	1985	1986	1987	1988	1989
1	4	<3	<3	12	4
1A	13	8	9	9	9
3	<3	2	1	3	3
3A	4	8	6	12	5
4	<3	-[d]	1	7	6
4A	33	12	13	20	17
5	56	20	82	192	131
9	4	3	2	5	4
11	55	143	20	67	42
12	4	2	1	7	7
13	4	<3	<3	5	<3
14	4	<3	<3	-[d]	<3
15	<3	<3	<3	4	4
20D	<3	2	2	3	2
20S	<3	1	1	4	2
21D	4	2	2	3	3
21S	<3	1	0.4	2	1
22D	<3	<3	<3	3	<3
23D	<3	<3	<3	4	<3
Background					
MML 17[e]	<3	<3	<3	3	4

[a]Data sources for 1985-1988 years are the annual site environmental reports for those years (Refs. 9-12). Background has not been subtracted.

[b]Sampling locations are shown in Figure 1-6.

[c]1 x 10^{-9} µCi/ml is equivalent to 1 pCi/L.

[d]Well was dry in all four quarters.

[e]Located at the Middlesex Municipal Landfill, Middlesex, NJ, approximately 0.8 km (0.5 mi) north of MSP.

TABLE 3-13

ANNUAL AVERAGE CONCENTRATIONS OF RADIUM-226

IN GROUNDWATER AT MSP, 1985-1989[a]

Sampling Location[b]	Concentration (10^{-9} µCi/ml)[c]				
	1985	1986	1987	1988	1989
1	0.5	0.2	0.3	0.3	0.9
1A	0.3	0.3	0.3	0.3	0.7
3	0.4	0.7	0.3	1.2	1.6
3A	0.6	0.5	0.5	0.9	1.0
4	0.2	-[d]	0.4	2.0	2.1
4A	0.3	0.5	0.6	1.0	0.9
5	0.5	0.4	0.6	2.4	2.4
9	0.7	0.8	0.8	2.8	7.0
11	0.7	0.6	0.5	4.1	4.7
12	0.3	0.3	0.3	2.3	2.2
13	0.1	0.2	0.4	0.3	0.7
14	0.2	0.1	0.1	-[d]	1.0
15	0.1	0.2	0.3	0.4	0.8
20D	0.4	0.5	0.8	0.8	0.8
20S	0.3	0.5	0.3	1.1	0.7
21D	0.7	0.4	0.4	0.9	0.7
21S	0.3	0.5	0.4	0.7	0.9
22D	0.3	0.3	0.4	0.3	0.7
23D	0.2	0.3	0.3	0.3	0.6
Background					
MML 17[e]	0.5	0.1	0.2	0.7	0.7

[a]Data sources for 1985-1988 are the annual site environmental reports for those years (Refs. 9-12). Background has not been subtracted.

[b]Sampling locations are shown in Figure 1-6.

[c]1×10^{-9} µCi/ml is equivalent to 1 pCi/L.

[d]Well was dry in all four quarters.

[e]Located at the Middlesex Municipal Landfill, Middlesex, NJ, 0.8 km (0.5 mi) north of MSP.

4.0 RELATED ACTIVITIES AND SPECIAL STUDIES

4.1 RELATED ACTIVITIES

Site security, maintenance, and monitoring continued.

4.2 SPECIAL STUDIES

There were no special studies at MSP in 1989.

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APPENDIX A
QUALITY ASSURANCE

QUALITY ASSURANCE

A comprehensive quality assurance (QA) program involving sampling, data management, and analysis was maintained to ensure that the data reported were representative of actual concentrations in the environment. The QA program meets the requirements of DOE Order 5700.6B and ANSI/ASME NQA-1.

QA sampling requirements were ensured through the following:

- Samples at all locations collected using established procedures
- Sampling program design provided for spikes, trip blanks, field blanks, and quality control (QC) duplicate sampling
- Chain-of-custody procedures implemented to maintain traceability of samples and corresponding analytical results

Data management QA was achieved through:

- Completion and recording of parameter-specific data review checklists for each analysis report
- Use of calculation sheets for constructing data tables and documenting computations
- Double-checking of and concurrence on calculations
  - By the originator
  - By an independent, equally qualified second party

System QA audits are conducted by BNI FUSRAP project QA personnel to verify adherence with laboratory procedures and to evaluate the appropriateness and effectiveness of the procedures. Audit team leaders and auditors are trained and certified in accordance with project procedures. Technical specialists participate as auditors under the direction of the audit team leader when warranted by the nature of the activities being audited. Audit reports are prepared for each audit conducted. Audit findings that require corrective action and followup are

documented, tracked, and resolved, as verified by the project QA supervisor.

Routine radioanalyses for the FUSRAP Environmental Monitoring Program were performed under subcontract by TMA/E, Albuquerque, New Mexico. This laboratory maintained an internal quality assurance program that involved routine calibration of counting instruments, source and background counts, routine yield determinations of radiochemical procedures, and replicate analyses to check precision. The accuracy of radionuclide determination was determined through the use of standards traceable to the National Institute of Standards and Technology (NIST), when available. When NIST standards were not available, standards from the New Brunswick Laboratory were used. The laboratory also participated in the Environmental Protection Agency's (EPA) Laboratory Intercomparison Studies Program. In this program, samples of different environmental media (water, milk, air filters, soil, foodstuffs, and tissue ash) containing one or more radionuclides in known amounts were prepared and distributed to the participating laboratories. After the samples were analyzed, the results were forwarded to EPA for comparison with known values and with the results from other laboratories. This program enabled the laboratory to regularly evaluate the accuracy of its analyses and take corrective action if needed. Table A-1 summarizes results of the EPA comparison studies for water samples. TMA/E has applied and been accepted for readmission into the DOE Laboratory Quality Assessment Program for Radioactive Materials, coordinated by the DOE Environmental Laboratory, New York, New York.

Interlaboratory comparison of the tissue-equivalent TLD results was provided by participation in the International Environmental Dosimeter Project sponsored jointly by DOE, NRC, and EPA.

Chemical analyses were performed under subcontract by Weston Analytical Laboratory, Lionsville, Pennsylvania. Weston's standard practices manual was reviewed and accepted by BNI. The laboratory maintains an internal QA program that involves the following.

For inorganic analyses, the program includes:

TABLE A-1

SUMMARY COMPARISON OF WATER SAMPLE RESULTS

(EPA and TMA/E)

Analysis and Sample Date	Value (pCi/L) EPA	Value (pCi/L) TMA/E	Ratio (TMA/E:EPA)[a]
Alpha			
1/89	41.0 ± 10.0	49.0 ± 1.0	1.20
4/89	8.0 ± 5.0	13.0 ± 1.0	1.63
6/89	30.0 ± 8.0	33.0 ± 2.7	1.10
7/89	29.0 ± 7.0	30.3 ± 2.1	1.04
11/89	4.0 ± 5.0	4.3 ± 0.6	1.08
Beta			
1/89	54.0 ± 5.0	53.0 ± 1.7	0.98
4/89	4.0 ± 5.0	5.3 ± 0.6	1.33
6/89	50.0 ± 5.0	58.3 ± 1.5	1.17
7/89	57.0 ± 5.0	51.0 ± 3.0	0.89
11/89	6.0 ± 5.0	6.7 ± 0.6	1.12
Ra-226			
1/89	5.0 ± 0.8	5.5 ± 0.3	1.10
3/89	3.50 ± 0.50	3.67 ± 0.06	1.05
5/89	4.90 ± 0.7	4.03 ± 0.25	0.82
7/89	3.50 ± 0.50	3.87 ± 0.15	1.11
10/89	17.7 ± 2.7	17.2 ± 0.5	0.97
Ra-228			
1/89	5.2 ± 0.8	6.1 ± 0.2	1.17
3/89	10.3 ± 1.5	11.3 ± 0.7	1.10
5/89	1.70 ± 0.30	1.77 ± 0.30	1.04
7/89	3.60 ± 0.50	5.20 ± 1.04	1.44
10/89	18.3 ± 2.7	24.8 ± 0.3	1.36
U (Natural)			
1/89	5.0 ± 6.0	5.3 ± 0.6	1.06
5/89	5.0 ± 6.0	5.0 ± 0.0	1.00
7/89	3.00 ± 6.00	3.00 ± 0.00	1.00
9/89	41.0 ± 6.0	39.7 ± 1.2	0.97

[a]This ratio can be used to determine the accuracy of TMA/E's analytical procedures.

- Initial calibration and calibration verification
- Continuing calibration verification•Reagent blank analyses
- Matrix spike analyses
- Duplicate sample analyses
- Laboratory control sample analyses
- Interlaboratory QA/QC

For organic analyses, the program includes:

- Gas chromatography/mass spectrometry instrumentation for both volatile and semivolatile compound analysis
- Initial multilevel calibration for each Hazardous Substances List (HSL) compound
- Matrix spike analyses
- Reagent blank analyses
- Interlaboratory QA/QC
- Continuing calibration for each HSL compound
- Addition of surrogate compounds to each sample and blanks for determining percent recovery information

Weston is currently an EPA-designated Contract Laboratory Program (CLP) laboratory for both organic and inorganic analyses. This requires passing EPA's blind performance evaluation testing each quarter. The technical specifications in BNI's subcontract with Weston specify QA/QC at, and in some cases beyond, the CLP level.

Currently, Weston participates in drinking water, wastewater, and/or hazardous waste certification programs. They are certified (or pending) in 35 such state programs including New Jersey. Continued certification hinges upon Weston's ability to pass regular performance evaluation testing.

Weston's QA program also includes an independent overview by their project QA coordinator and a corporate vice president who audits their program activities quarterly.

APPENDIX B

ENVIRONMENTAL STANDARDS AND CONVERSION FACTORS

ENVIRONMENTAL STANDARDS

The DOE long-term radiation protection standard of 100 mrem/yr above background level includes exposure from all pathways except medical treatments (Ref. 15). Evaluation of exposure pathways and resulting dose calculations is based on assumptions such as occupancy factors in determining the dose from external gamma radiation; subtraction of background concentrations of radionuclides in air, water, and soil before calculating dose; closer review of water use, using the data that most closely represent actual exposure conditions rather than maximum values as applicable; and using average consumption rates of food and water per individual rather than maximums. Use of such assumptions will result in calculated doses that more accurately reflect the exposure potential from site activities.

TABLE B-1

CONVERSION FACTORS

1 year	=	8,760 hours
1 L	=	1,000 ml
1 μCi	=	1,000,000 pCi
1 pCi	=	0.000001 μCi
1 pCi/L	=	10^{-9} μCi/ml
1 pCi/L	=	0.000000001 μCi/ml
1 μCi/ml	=	1,000,000,000 pCi/L
10^{-6}	=	0.000001
10^{-7}	=	0.0000001
10^{-8}	=	0.00000001
10^{-9}	=	0.000000001
10^{-10}	=	0.0000000001
7×10^{-10}	=	0.0000000007
1 gal	=	3.785 L
1 yd^3	=	0.765 m^3
1 ft	=	0.3048 m

APPENDIX C
ABBREVIATIONS AND ACRONYMS

ABBREVIATIONS

cm	centimeter
cm/sec	centimeters per second
ft	foot
ft msl	feet above mean sea level
g	gram
gal	gallon
h	hour
ha	hectare
in.	inch
km	kilometer
km/h	kilometers per hour
lb	pound
m	meter
m^3	cubic meter
mg	milligram
mg/L	milligrams per liter
mi	mile
ml	milliliter
mph	miles per hour
mrem	millirem
mrem/yr	millirem per year
µCi/ml	microcuries per milliliter
µg/L	micrograms per liter
µmhos/cm	micromhos per centimeter
pCi	picocurie
pCi/g	picocuries per gram
pCi/L	picocuries per liter
yd^3	cubic yard
yr	year

ACRONYMS

AEC	Atomic Energy Commission
BNI	Bechtel National, Inc.
CLP	Contract Laboratory Program
DOE	Department of Energy
EPA	Environmental Protection Agency
FUSRAP	Formerly Utilized Sites Remedial Action Program
HSL	Hazardous Substances List
MED	Manhattan Engineer District
MML	Middlesex Municipal Landfill
MSP	Middlesex Sampling Plant
NIST	National Institute of Standards and Technology
NJDEP	New Jersey Department of Environmental Protection
QA	quality assurance
QC	quality control
TLD	thermoluminescent dosimeter
TMA/E	Thermo Analytical/Eberline
TOC	total organic carbon
TOX	total organic halides

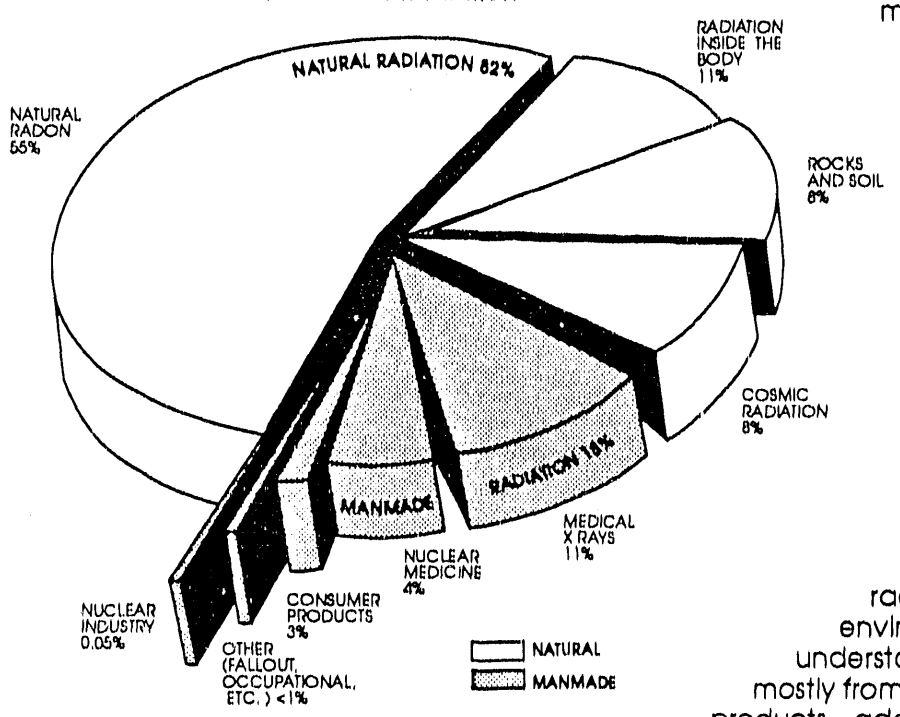
APPENDIX D

RADIATION IN THE ENVIRONMENT

Radiation is a natural part of our environment. When our planet was formed, radiation was present—and radiation surrounds it still. Natural radiation showers down from the distant reaches of the cosmos and continuously radiates from the rocks, soil, and water on the Earth itself.

During the last century, mankind has discovered radiation, how to use it, and how to control it. As a result, some manmade radiation has been added to the natural amounts present in our environment.

Sources of Radiation



Many materials—both natural and manmade—that we come into contact with in our everyday lives are radioactive. These materials are composed of atoms that release energetic particles or waves as they change into more stable forms. These particles and waves are referred to as *radiation*, and their emission as *radioactivity*.

As the chart on the left shows, most environmental radiation (82%) is from natural sources. By far the largest source is radon, an odorless, colorless gas given off by natural radium in the Earth's crust. While radon has always been present in the environment, its significance is better understood today. Manmade radiation—mostly from medical uses and consumer products—adds about eighteen percent to our total exposure.

TYPES OF IONIZING RADIATION

Radiation that has enough energy to disturb the electrical balance in the atoms of substances it passes through is called *ionizing radiation*. There are three basic forms of ionizing radiation.

Alpha

Alpha particles are the largest and slowest moving type of radiation. They are easily stopped by a sheet of paper or the skin. Alpha particles can move through the air only a few inches before being stopped by air molecules. However, alpha radiation is dangerous to sensitive tissue inside the body.

Beta

Beta particles are much smaller and faster moving than alpha particles. Beta particles pass through paper and can travel in the air for about 10 feet. However, they can be stopped by thin shielding such as a sheet of aluminum foil.

Gamma

Gamma radiation is a type of electromagnetic wave that travels at the speed of light. It takes a thick shield of steel, lead, or concrete to stop gamma rays. X rays and cosmic rays are similar to gamma radiation. X rays are produced by manmade devices; cosmic rays reach Earth from outer space.

Units of Measure

Radiation can be measured in a variety of ways. Typically, units of measure show either 1) the total amount of radioactivity present in a substance, or 2) the level of radiation being given off.

The radioactivity of a substance is measured in terms of the number of transformations (changes into more stable forms) per unit of time. The *curie* is the standard unit for this measurement and is based on the amount of radioactivity contained in 1 gram of radium. Numerically, 1 curie is equal to 37 billion transformations per second. The amounts of radioactivity that people normally work with are in the millicurie (one-thousandth of a curie) or microcurie (one-millionth of a curie) range. Levels of radioactivity in the environment are in the picocurie, or pCi (one-trillionth of a curie) range.

Levels of radiation are measured in various units. The level of gamma radiation in the air is measured by the *roentgen*. This is a relatively large unit, so measurements are often calculated in milliroentgens. Radiation absorbed by humans is measured in either *rad* or *rem*. The rem is the most descriptive because it measures the ability of the specific type of radiation to do damage to biological tissue. Again, typical measurements will often be in the millirem (mrem), or one-thousandth of a rem, range. In the international scientific community, absorbed dose and biological exposure are expressed in *grays* and *selverts*. 1 gray (Gy) equals 100 rad. 1 selvert (Sv) equals 100 rem. On the average, Americans receive about 360 mrem of radiation a year. Most of this (97%) is from natural radiation and medical exposure. Specific examples of common sources of radiation are shown in the chart below.

RADIATION IN THE ENVIRONMENT

Because the radioactivity of individual samples varies, the numbers given here are approximate or represent an average. They are shown to provide a perspective for concentrations and levels of radioactivity rather than dose.

mrem = millirem
pCi = picocurie

Cosmic Radiation

Cosmic radiation is high-energy gamma radiation that originates in outer space and filters through our atmosphere.

Sea Level ..... 26 mrem/year
(increases about 1/2 mrem for each additional 100 feet in elevation)
Atlanta, Georgia (1,050 feet) ..... 31 mrem/year
Denver, Colorado (5,300 feet) ..... 50 mrem/year
Minneapolis, Minnesota (815 feet) ..... 30 mrem/year
Salt Lake City, Utah (4,400 feet) ..... 46 mrem/year

Terrestrial Radiation

Terrestrial sources are naturally radioactive elements in the soil and water such as uranium, radium, and thorium. Average levels of these elements are 1 pCi/gram of soil.

United States (average) ..... 26 mrem/year
Denver, Colorado ..... 63 mrem/year
Nile Delta, Egypt ..... 350 mrem/year
Paris, France ..... 350 mrem/year
Coast of Kerala, India ..... 400 mrem/year
McAlpe, Brazil ..... 2,558 mrem/year
Pocos De Caldas, Brazil ..... 7,000 mrem/year

Buildings

Many building materials, especially granite, contain naturally radioactive elements.

U.S. Capitol Building ..... 85 mrem/year
Base of Statue of Liberty ..... 325 mrem/year
Grand Central Station ..... 525 mrem/year
The Vatican ..... 800 mrem/year

Radon

Radon levels in buildings vary, depending on geographic location, from 0.1 to 200 pCi/liter.

Average Indoor Radon Level ..... 1.5 pCi/liter
Occupational Working Limit ..... 100.0 pCi/liter

Food

Food contributes an average of 20 mrem/year, mostly from potassium-40, carbon-14, hydrogen-3, radium-226, and thorium-232.

Beer ..... 390 pCi/liter
Tap Water ..... 20 pCi/liter
Milk ..... 1,400 pCi/liter
Salad Oil ..... 4,900 pCi/liter
Whiskey ..... 1,200 pCi/liter
Brazil Nuts ..... 14 pCi/g
Bananas ..... 3 pCi/g
Flour ..... 0.14 pCi/g
Peanuts & Peanut Butter ..... 0.12 pCi/g
Tea ..... 0.40 pCi/g

Medical Treatment

The exposures from medical diagnosis vary widely according to the required procedure, the equipment and film used for x rays, and the skill of the operator.

Chest X Ray ..... 10 mrem
Dental X Ray, Each ..... 100 mrem

Consumer Goods

Cigarettes-two packs/day (polonium-210) ..... 8,000 mrem/year
Color Television ..... <1 mrem/year
Gas Lantern Mantle (thorium-232) ..... 2 mrem/year
Highway Construction ..... 4 mrem/year
Airplane Travel at 39,000 feet (cosmic) ..... 0.5 mrem/hour
Natural Gas Heating and Cooking (radon-222) ..... 2 mrem/year
Phosphate Fertilizers ..... 4 mrem/year

Natural Radioactivity in Florida Phosphate Fertilizers (in pCi/gram)

	Normal Superphosphate	Concentrated Superphosphate	Gypsum
Ra-226	21.3	21.0	33.0
U-238	20.1	58.0	6.0
Th-230	18.9	48.0	13.0
Th-232	0.6	1.3	0.3

Porcelain Dentures (uranium) ..... 1,500 mrem/year
Radioluminescent Clock (promethium-147) ..... <1 mrem/year
Smoke Detector (americium-241) ..... 0.01 mrem/year

International Nuclear Weapons Test Fallout from pre-1980 atmospheric tests (average for a U.S. citizen) ..... 1 mrem/year

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PERSPECTIVE: How Big is a Picocurie?

The *curie* is a standard measure for the intensity of radioactivity contained in a sample of radioactive material. It was named after French scientists Marie and Pierre Curie for their landmark research into the nature of radioactivity.

The basis for the curie is the radioactivity of one gram of radium. Radium decays at a rate of about 2.2 trillion disintegrations ($2.2X10^{12}$) per minute. A *picocurie* is one trillionth of a curie. Thus, a picocurie represents 2.2 disintegrations per minute.

To put the relative size of one *trillionth* into perspective, consider that if the Earth were reduced to one trillionth of its diameter, the "pico earth" would be smaller in diameter than a speck of dust. In fact, it would be six times smaller than the thickness of a human hair.

The difference between the curie and the picocurie is so vast that other metric units are used between them. These are as follows:

Millicurie = $\frac{1}{1,000}$ **(one thousandth) of a curie**

Microcurie = $\frac{1}{1,000,000}$ **(one millionth) of a curie**

Nanocurie = $\frac{1}{1,000,000,000}$ **(one billionth) of a curie**

Picocurie = $\frac{1}{1,000,000,000,000}$ **(one trillionth) of a curie**

The following chart shows the relative differences between the units and gives analogies in dollars. It also gives examples of where these various amounts of radioactivity could typically be found. The number of disintegrations per minute has been rounded off for the chart.

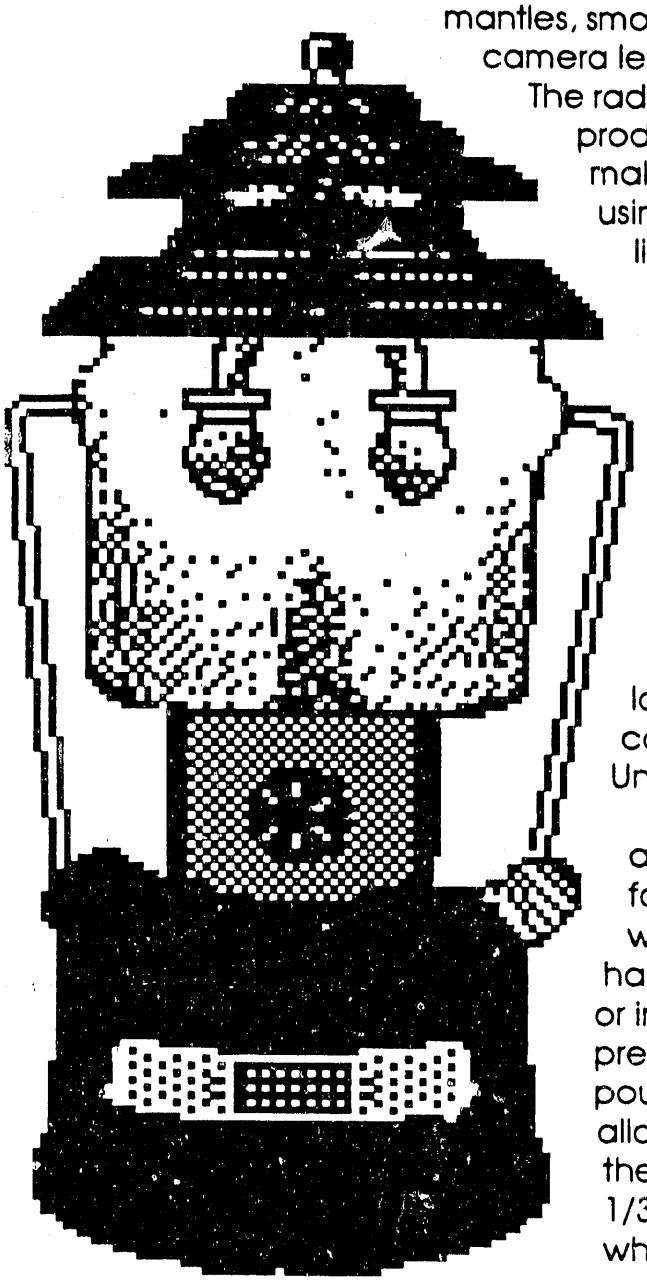
UNIT OF RADIOACTIVITY	SYMBOL	DISINTEGRATIONS PER MINUTE	DOLLAR ANALOGY	EXAMPLES OF RADIOACTIVE MATERIALS
1 Curie	Ci	$2x10^{12}$ or 2 Trillion	2 Times the Annual Federal Budget	Nuclear Medicine Generator
1 Millicurie	mCi	$2x10^{9}$ or 2 Billion	Cost of a New Interstate Highway from Atlanta to San Francisco	Amount Used for a Brain or Liver Scan
1 Microcurie	µCi	$2x10^{6}$ or 2 Million	All-Star Baseball Player's Salary	Amount Used in Thyroid Tests
1 Nanocurie	nCi	$2x10^{3}$ or 2 Thousand	Annual Home Energy Costs	Consumer Products
1 Picocurie	pCi	2	Cost of a Hamburger and Coke	Background Environmental Levels

Chart provided by W.L. Beck, Bechtel National, Inc.

PERSPECTIVE: Radioactivity in Gas Lantern Mantles

Around the House

Many household products contain a small amount of radioactivity. Examples include gas lantern mantles, smoke detectors, dentures, camera lenses, and anti-static brushes. The radioactivity is added to the products either specifically to make them work, or as a result of using compounds of elements like thorium and uranium in producing them. The amount of radiation the products gives off is not considered significant. But with today's sensitive equipment, it can be detected.



Lanterns: In a New Light

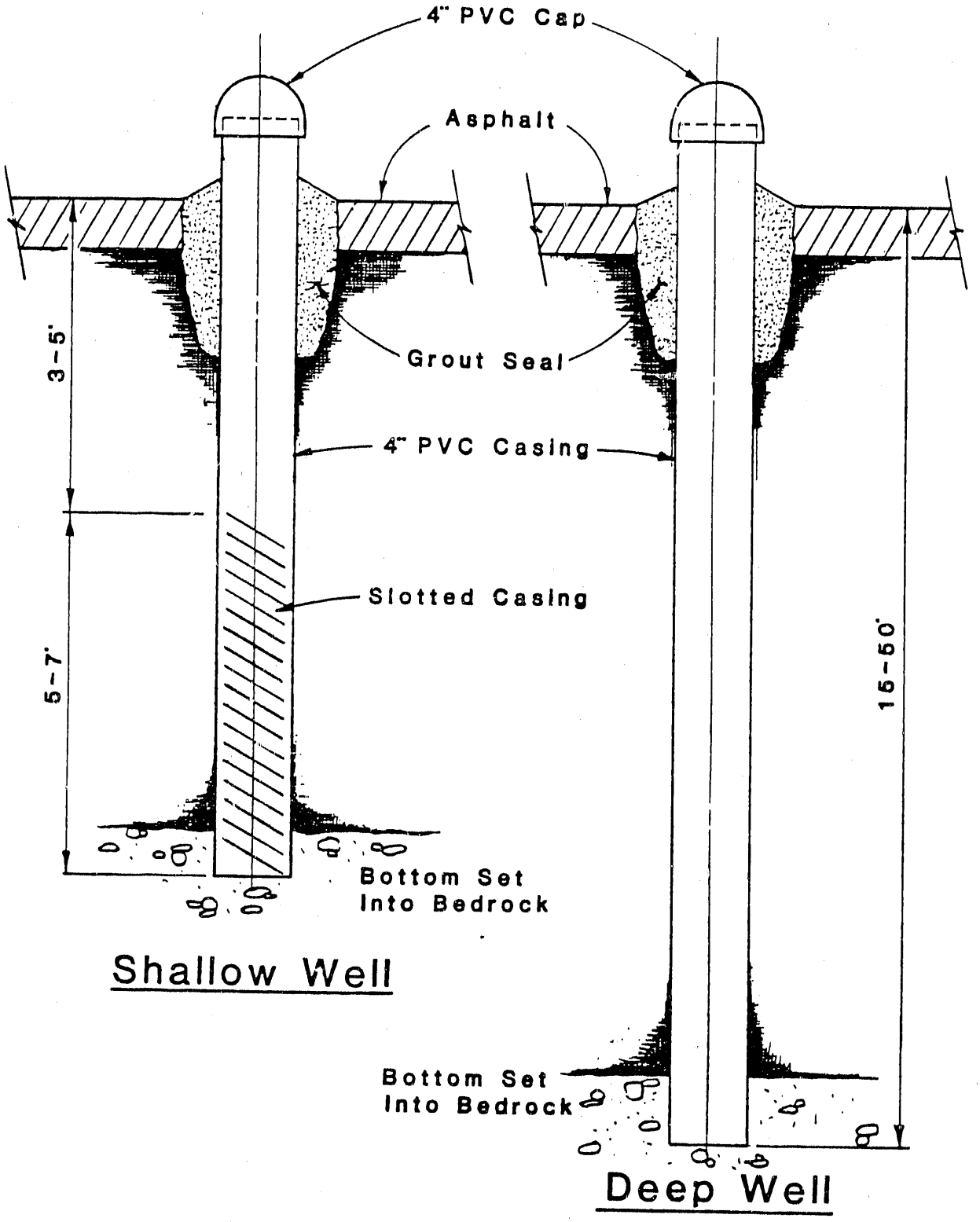
About 20 million gas lantern mantles are used by campers each year in the United States.

Under today's standards, the amount of natural radioactivity found in a lantern mantle would require precautions in handling it at many Government or industry sites. The radioactivity present would contaminate 15 pounds of dirt to above allowable levels. This is because the average mantle contains 1/3 of a gram of thorium oxide, which has a specific activity (a measure of radioactivity) of approximately 100,000 picocuries per gram. The approximately 35,000 picocuries of radioactivity in the mantle would, if thrown onto the ground, be considered low-level radioactive contamination.

From information provided by W.L. Beck, Bechtel National, Inc.

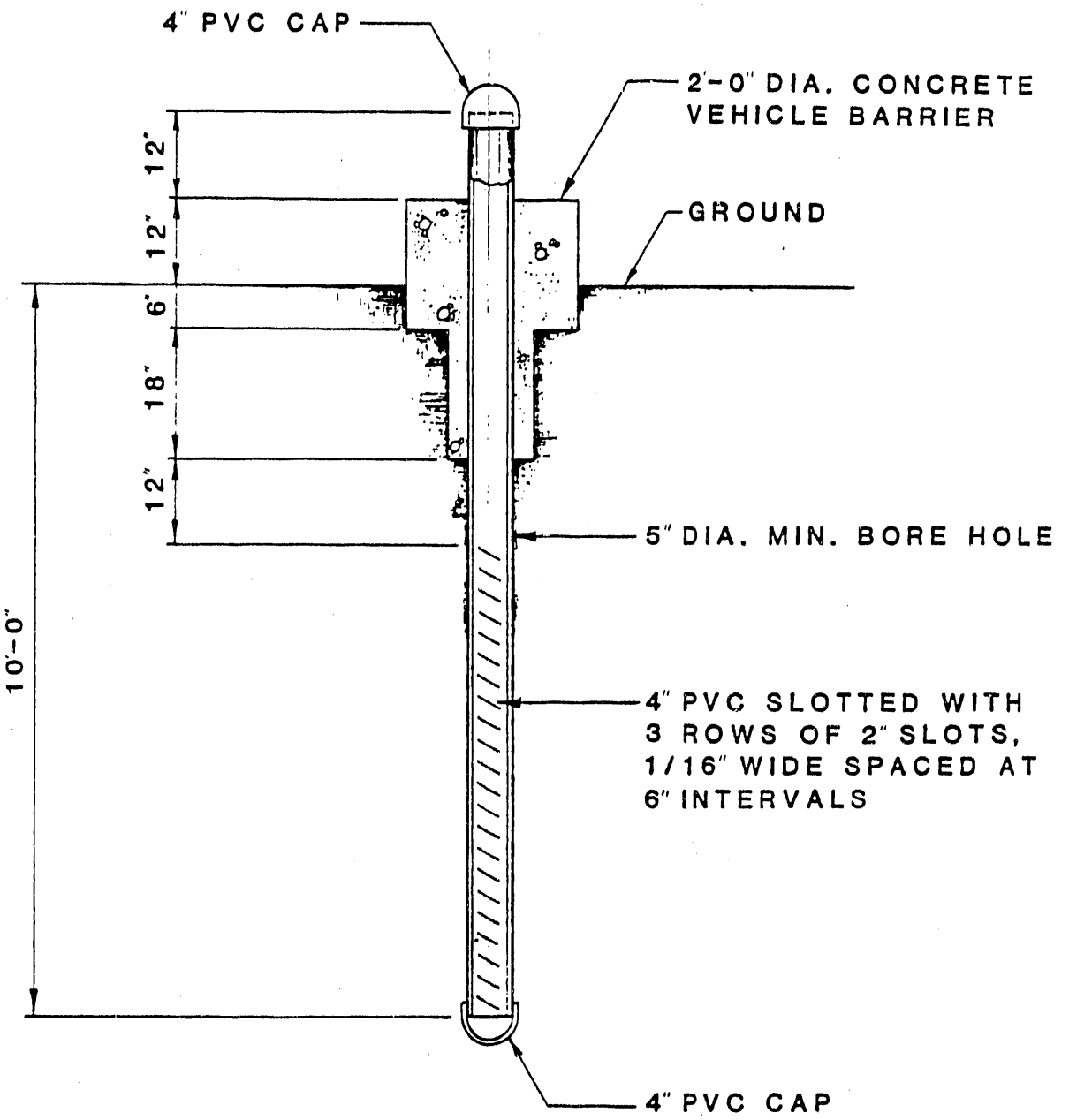
APPENDIX E

WELL CONSTRUCTION LOG



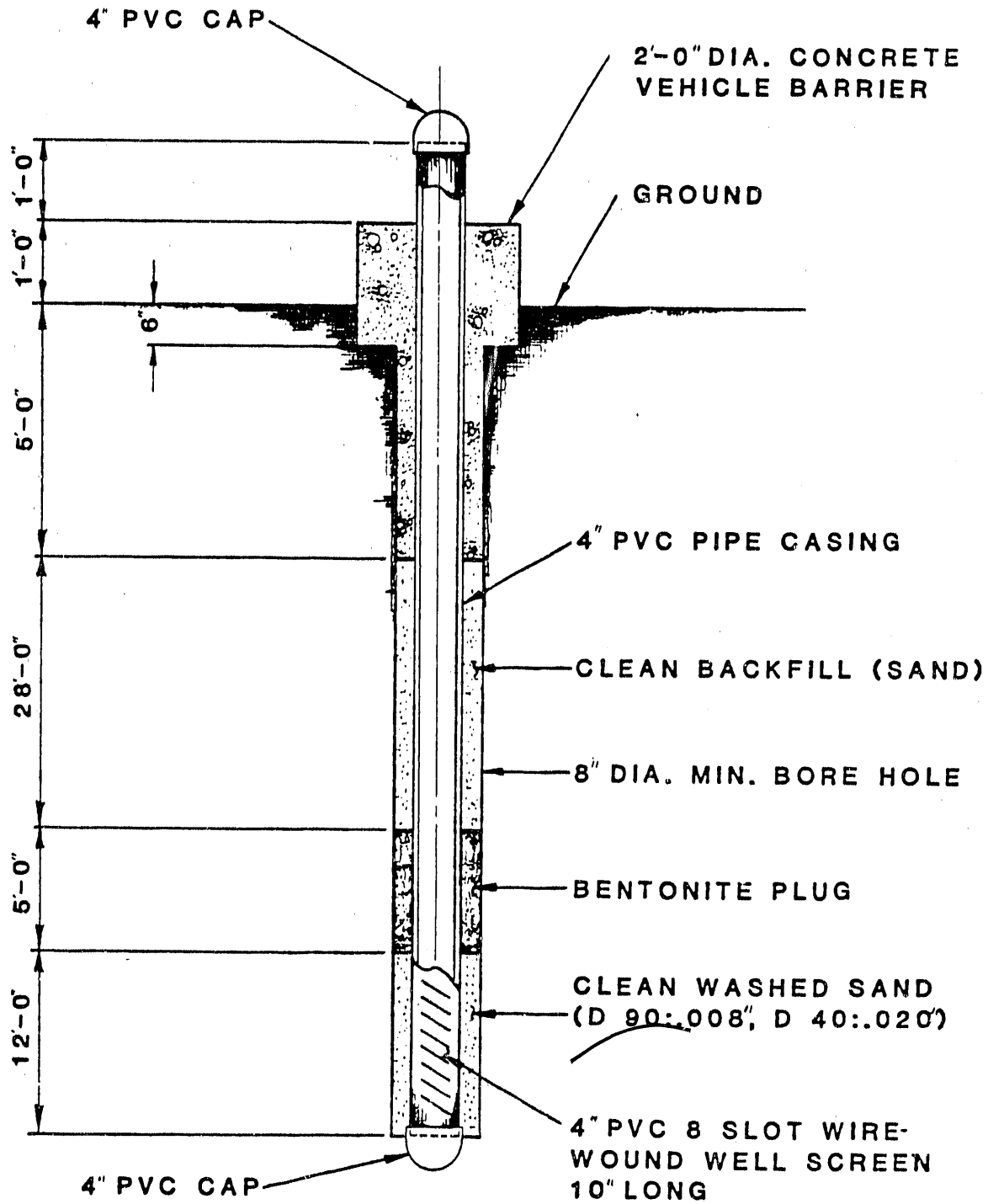
MONITORING WELL INSTALLATION DETAIL

PHASE I



SHALLOW MONITORING WELL INSTALLATION DETAIL

(PHASE II)



DEEP MONITORING WELL INSTALLATION DETAIL

(PHASE II)

APPENDIX F

DISTRIBUTION LIST FOR MIDDLESEX SAMPLING PLANT ENVIRONMENTAL REPORT FOR CALENDAR YEAR 1989

END

DATE FILMED

12/18/90