Brookfield Ave LF RI Report 07/30/98
9/98

Executive Summary

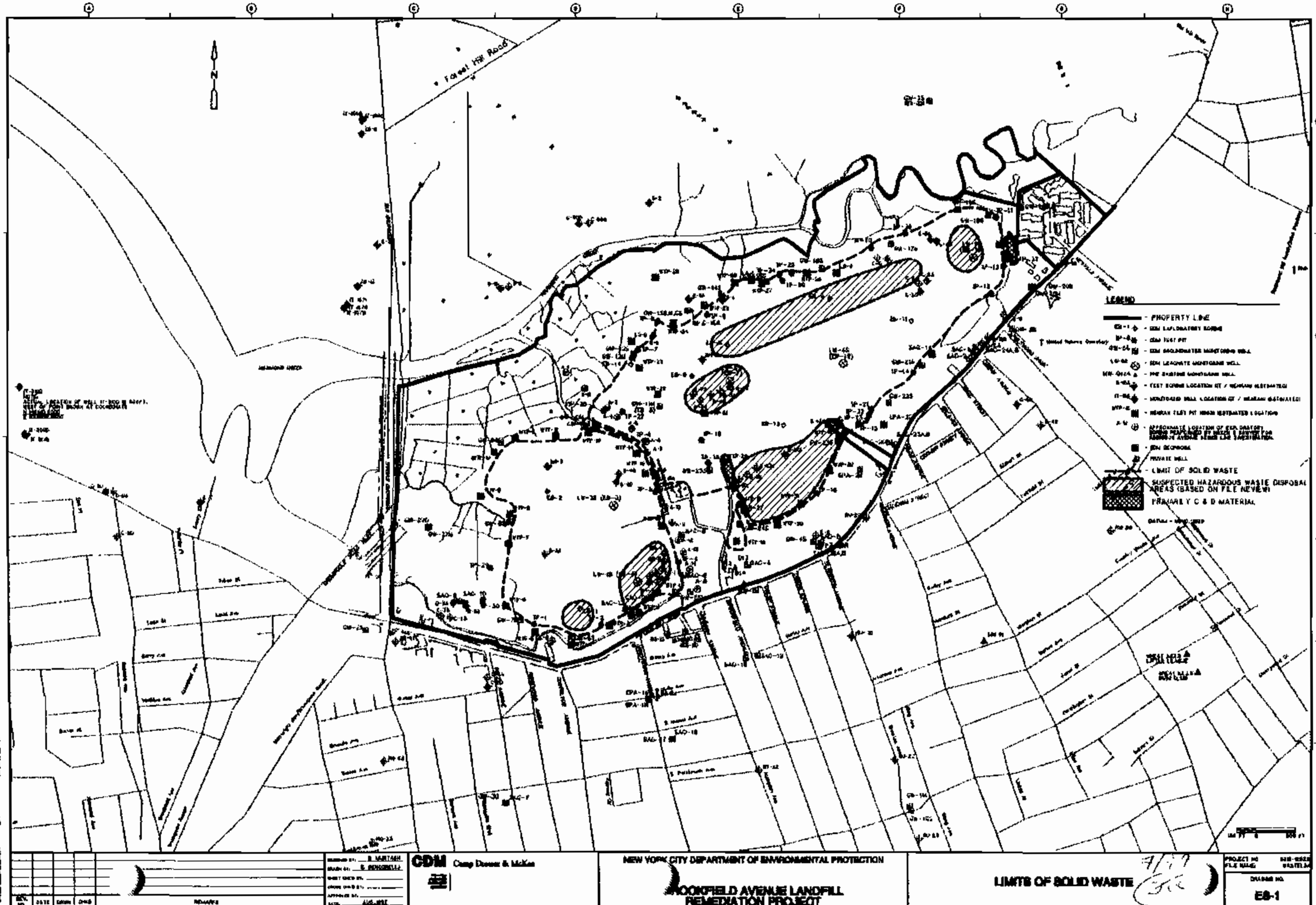
The Brookfield Avenue Landfill is located near the Richmond and Great Kills Sections of Staten Island, New York. It is bounded to the south by Arthur Kill Road and to the west by Richmond Avenue. The landfill, which was plotted as Section 10 and 11 of the Fresh Kills Landfill, was operated by the City of New York from 1966 through 1980. During that period, it received approximately 5.1 million cubic yards of municipal solid waste. Industrial and hazardous waste dumping also occurred at this site. Approximately 132 acres of the 272 acre site contain solid waste. The waste pile rises to an elevation of 45 feet above mean sea level. Other City facilities have been added to the site since the landfill operations stopped in 1980. These include centralized wastewater collection systems (i.e. interceptor), the Eltingville wastewater pump station, and a number of storm sewer outfalls.

The site is presently classified by the New York State Department of Environmental Conservation (NYSDEC) as a Class 2 inactive hazardous waste site. Per an Order on Consent from the NYSDEC dated April 7, 1992, the City of New York was required to develop and implement a remedial program for the Brookfield Avenue Landfill. On March 23, 1993, Camp Dresser & McKee (CDM) was retained by NYCDEP to implement a Remedial Investigation/Feasibility Study (RI/FS) and remedial design for the site.

The purposes of the RI were to investigate the nature and extent of contamination from the Brookfield Avenue Landfill, and to assess the hazards to human health and the environment that may be attributable to site-related contaminants. This RI was designed to augment previous studies and move forward the selection of the ultimate remedial action alternative in a timely and cost effective manner. To achieve these objectives, nine RI tasks were performed to evaluate various media: waste characterization, hydrogeologic characterization, leachate characterization, landfill gas characterization, ambient air characterization, Richmond Creek water and sediment characterization, ecological assessment, radiological assessment and baseline human health and ecological risk assessments.

Phase I of the field investigations were performed from December 1993 through July 1994. The Phase I activities are described in the original project work plan dated August 1993. The Phase II field investigations were performed from December 1996 through December 1997. Phase II included followup study activities recommended by the City, NYSDEC, USEPA, and the community. The Phase III field investigations began in January 1998 and concluded in May 1998. The Phase III investigations included (1) additional acute, chronic, and bioaccumulation studies to better evaluate Richmond Creek sediment toxicity and (2) three additional deep monitoring wells in the Cretaceous aquifer to better evaluate the connection between the Upper Glacial and Cretaceous aquifers. Independent validation of the Phase I and Phase II analytical results was completed in March 1998.

Major conclusions based on the results of these investigations are summarized as follows:


LEGEND
PROPERTY LINE
LIMIT OF SOLID WASTE
SUSPECTED HAZARDOUS WASTE DISPOSAL AREAS (BASED ON FILE REVIEW)
PRIMARY C & D MATERIAL
Forest Hill Road
CDM Camp Dresser & McKee
NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION
BROOKFIELD AVENUE LANDFILL REMEDIATION PROJECT
LIMITS OF SOLID WASTE
REMARKS
ES-1

- The northern portion of the site (in the vicinity of Richmond Creek) is a local discharge area for the Cretaceous aquifer. Here the Cretaceous leaks upward to the Upper Glacial aquifer and eventually into Richmond Creek. Over the rest of the site, the Upper Glacial aquifer leaks downward into the Cretaceous aquifer. This results in a very complex local flow pattern in the Cretaceous aquifer.

- The Upper Glacial aquifer near Richmond Creek is moderately influenced by tidal fluctuations in the Creek, however, the influences are not strong enough to reverse flow directions over any significant areas. Tidal influences in the Cretaceous aquifer are slight and insignificant.

- Downward leakage is likely greatest in the vicinity of Arthur Kill Road where leaky confining units are thinnest. Head measurements from three additional deep monitoring wells installed near Arthur Kill Road confirmed a downward gradient. Trace concentrations of VOCs and ammonia indicate that the leakage to the Cretaceous aquifer is minimal.

Leachate Characterization

- The Brookfield Avenue Landfill generates approximately 95,000 gallons of leachate per day. Approximately 92,000 gallons per day (96.5%) of the leachate discharge to the local surface water bodies such as Richmond Creek and associated wetlands. It is estimated that approximately 3,500 gallons per day of leachate (3.5%) leak into the Cretaceous aquifer. Because of the complex flow pathway from the Upper Glacial to the Cretaceous, the leakage estimate of 3,500 gpd is considered a simple estimate. Nevertheless, being extremely conservative, the leakage rate is still estimated to be less than 10 percent.

- The leachate within the landfill is of moderate strength and does result in water quality standard contraventions in the Upper Glacial aquifer onsite and the Richmond Creek segment adjacent to the landfill.

Groundwater Quality Characterization

- Shallow groundwater at the perimeter of the solid waste mound has been contaminated by the landfill. This contamination extends to Richmond Creek. Exceedances of Standards, Criteria, or Guidance (SCG) in the Upper Glacial aquifer and leachate mound includes: 13 volatile organic compounds (VOCs), 17 semi-volatile organic compounds (SVOCs), 8 pesticides, 2 polychlorinated biphenyls (PCBs) and 13 metals. The extent of landfill impacted groundwater quality is shown in Figure ES-3.

- The most frequently detected contaminants in the shallow groundwater include: benzene, chlorobenzene, toluene, xylene, dichlorobenzene, napthalene, 4,4-DDE, copper, iron, lead, manganese, sodium, zinc, ammonia, bromide, chloride, and sulfate.

- No VOC, SVOC or pesticides contamination was detected offsite in the Upper Glacial aquifer.

- Vertical leakage of contamination from the shallow sands to the lower portion of the Upper Glacial aquifer occurs in the southwest area (near SAC-9), the northern corridor between the two cells (near GW-10M and GW-11M) and the Holterman's Bakery area (SAC-20).

- It is estimated that small percentages of the leachate (approximately 3-4%) leak into the Cretaceous aquifer. Because of the long travel path, contaminants in the leachate undergo significant attenuation as they migrate from the Upper Glacial to the Cretaceous aquifer. This is primarily due to dispersion and sorption. Wells screened in the Cretaceous aquifer that show very low levels of leachate indicators include GW-29, SAC-10, SAC-23B, SAC-24B and D-13. SCGs are slightly exceeded for acetone, chloroform, toluene and chlorobenzene.

Air Characterization

- In general, the upwind-downwind ambient air data suggest that the Brookfield Avenue Landfill is not a significant source of most VOCs. The range of values for samples taken upwind of the landfill are of comparable magnitude to the values taken at downwind ambient air sampling stations. Exceptions to this include some of the methane related compounds (dichlorodiflouromethane, trichlorofluoromethane, chloroethane), as well as possibly benzene. Although the flux box data show that the landfill is emitting VOCs, the magnitude of the emissions is not large enough to be registered as a significant change between upwind and downwind concentrations.

- The flux box emission sampling and modeling results suggest that the Brookfield Avenue Landfill is a minor source of benzene, 2-hexanone, tetrachloroethylene, carbon tetrachloride and trichloroethylene. Acrolein and acrylonitrile were estimated, based on flux box emission sampling and modeling, to be found offsite at concentrations approaching 24% and 45%, respectively, of the ambient guideline concentration (AGC). Even though flux box emission samples and air dispersion modeling suggest that Brookfield is a source of acrolein and acrylonitrile in ambient air, this was not confirmed by the upwind-downwind ambient air sample analysis.

- The Brookfield Avenue Landfill is not a significant source of inhalable particulates. PM-10 data for all four rounds were not found to exceed the Federal 24-hour standard for inhalable particulates of 150 ug/m^3. In comparing the ambient air results, which were taken over a 24 hour period, to the annual standard, several samples do exceed the annual PM-10 standard of 50 ug/m^3, although only one sample location (AA-2) has an average concentration (based on the four rounds) slightly greater than the annual standard. No upwind-downwind relationship is apparent from the data. Higher concentration samples were just as likely to appear upwind as they were downwind. Because Brookfield is well vegetated, it is not considered a significant source of these particulates.

- Hydrogen sulfide and mercaptans were not detected in the landfill surface emission samples. They were found at very low levels in landfill gas within the landfill.

- Based on a landfill gas generation model estimate, the Brookfield Avenue Landfill, under anaerobic conditions, would generate approximately 500 to 760 standard cubic feet per minute (scfm) of gas during the constant phase of gas generation. Currently, this is not expected to be the case due to significant infiltration of air into the waste mass. Flux box and passive vent measured emission rates confirmed that gas generation rates are not as high as would be expected under anaerobic conditions. Internal landfill gas sampling indicated that ambient air makes up between 20 and 60% of the gas. Gas generation rates are expected to increase, indicating a moderate amount of toxicity. Richmond Creek sediments were not found to be toxic to the polychaete worm or mollusc, based on their greater than 90% survival during the 28 day (chronic) testing. However, tissue analysis indicated an increased uptake of arsenic, cadmium, chromium, mercury and nickel in the mollusc and copper in the worm, compared to the control exposures.

Ecological Assessment

- No unique or unusual floral assemblages were noted at the site. Field reconnaissance confirmed the presence of previously identified wetlands with some minor modification of their boundaries.

- The northern tidal marsh portion of the Brookfield Avenue Landfill is part of Fresh Kills, a significant Fish and Wildlife Habitat, as designated by New York State's Coastal Management Program (CMP). The area was first listed as a Significant Habitat in September of 1992 and was assigned the highest Significance Value of the five Significant Habitats located on the north and west side of Staten Island, as determined by the CMP. It was awarded a high score in the species vulnerability category due to its use as a wintering area by the northern harrier (threatened) and long-eared owl, and as a nesting area by the barn owl (special concern species). Until the mid-1980's, a number of short eared owls (special concern species) were known to winter in the area. Additionally, the diamondback terrapin (special concern species) was observed in 1967, but has not been confirmed since.

- The vegetative community on the capped portion of the landfill is distinctively different from that on the uncapped portion. Capped areas contain grasses and weeds that appear highly stressed. Stunted and sporadic vegetation on the capped portion may be a result of the pyritic clays used in the capping system rather than from landfill related contamination. Individual plants appear stunted and little woody vegetation is evident. Many bare spots and erosional valleys exist on the summit and slopes of the capped portion. Conversely, dense stands of tall reed dominate much of the uncapped area and signs of stress are not as evident.

- The plant community of the landfill provides potential moderate quality habitat for small birds and mammals, however, it does not constitute a major food resource for wildlife. Although some species produce nuts, berries, or fruits, they are quite scarce. No rare, threatened or endangered plants, and no plant species of special concern are known to occur onsite.

- Richmond Creek, in the vicinity of the Brookfield Avenue Landfill, is subject to widely ranging water quality characteristics (e.g., pH, salinity, temperature), depending on tide and distance downstream from the weir just east of Arthur Kill Road.

Contaminant Fate and Transport

- Contaminant transport in the Upper Glacial aquifer is predominately limited to the site. These contaminants discharge to Richmond Creek. Because of the close proximity of the landfill to the creek, little contaminant attenuation occurs in the aquifer before discharge. The exceptions to this are semi-volatile contaminants, most metals, and PCBs which are strongly sorbed to the waste aquifer material limiting migration in the groundwater pathway.

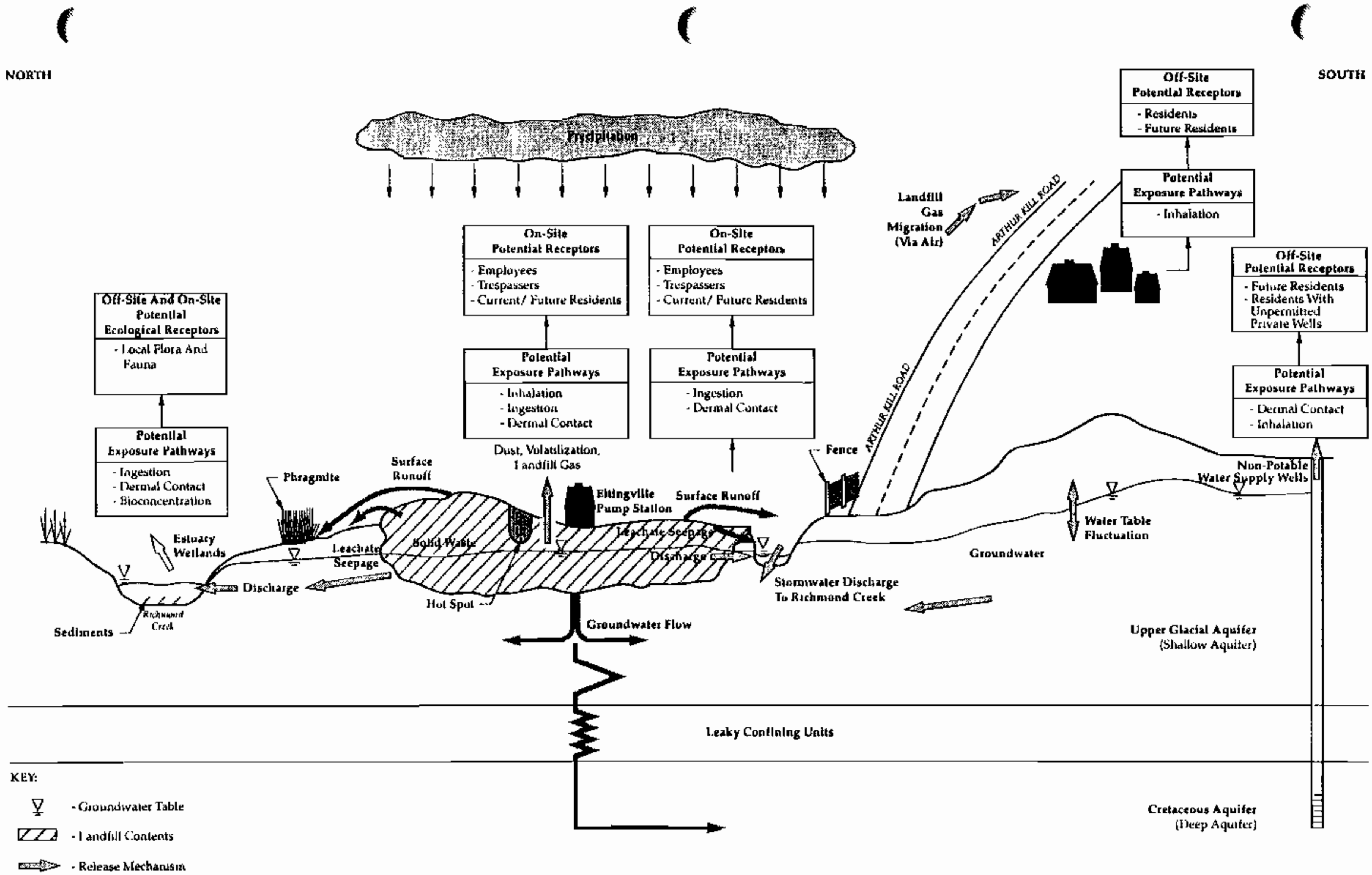


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Figure ES-4
Conceptual Model of Contaminant Sources, Potential Migration Pathways, and Receptors
Brookfield Avenue Landfill Remediation Project

7/17 (JC)

- Data from the six nearfield sediment and surface water sample locations does not implicate any particular area of the landfill as most likely contributing to the estimated ecological risk. Except for a group of pesticides detected from SW-4, the observed contaminants appeared consistently in a majority of the sediment and surface water samples, and at similar concentrations. The weight of evidence suggests that the entire landfill should be considered a source of area of contamination to Richmond Creek.

Identification of Data Gaps

The following data gaps were identified based on the results of the Remedial Investigation. The significance of these data gaps is also discussed.

- **Regional flow direction and pattern of the Cretaceous aquifer system.**

  The flow patterns in the Cretaceous aquifer are extremely complex. Even after collecting and evaluating significant quantities of Cretaceous data in the Brookfield area, the regional flow patterns remain somewhat uncertain because of a lack of regional data. Because the rate of leakage of Brookfield leachate to the Cretaceous aquifer is low, little leachate contamination was observed in the Cretaceous. This aquifer is not used for potable supply; thus, this gap is not an immediate concern and will not influence the remedy selection process.

- **Confirmation that landfill gas is not migrating in the soil south of Arthur Kill Road.**

  Several local areas near the south boundary of the site have periodically detected peak soil gas concentrations in excess of 100 percent LEL. While the location of these local areas suggest that the readings are not related to landfill gas, additional data needs to be collected to confirm this. This data gap is significant to the remedy design and will be addressed during the Feasibility Study.

- The NYSDEC's Division of Fish and Wildlife has requested resident biota sampling with tissue analysis for PCBs and mercury and additional sediment sampling in freshwater wetland AR-53 for PCB's, due to the close proximity of samples containing these contaminants to surface waters.

  Regarding this data gap, the NYCDEP will continue to work with the NYSDEC to develop a scope for this testing and carry out the biota sampling.

Recommendations

- The findings and conclusions of this Remedial Investigation are sufficient to proceed to the next phase of the remedy selection process, the feasibility study. It is recommended that the NYSDEC authorize the start of the feasibility study. The feasibility study should address institutional controls restricting well development in the area and future land uses for the site, containment of wastes, control of leachate discharge to surface waters and the Cretaceous aquifer, control of landfill gas emissions, and focused remediation of contamination source areas within the waste mound.

- The hot spot no. 5 area presents a significant exposure pathway with its surface seep of waste oils containing PCBs and pesticides. In addition, it represents a concentrated contamination

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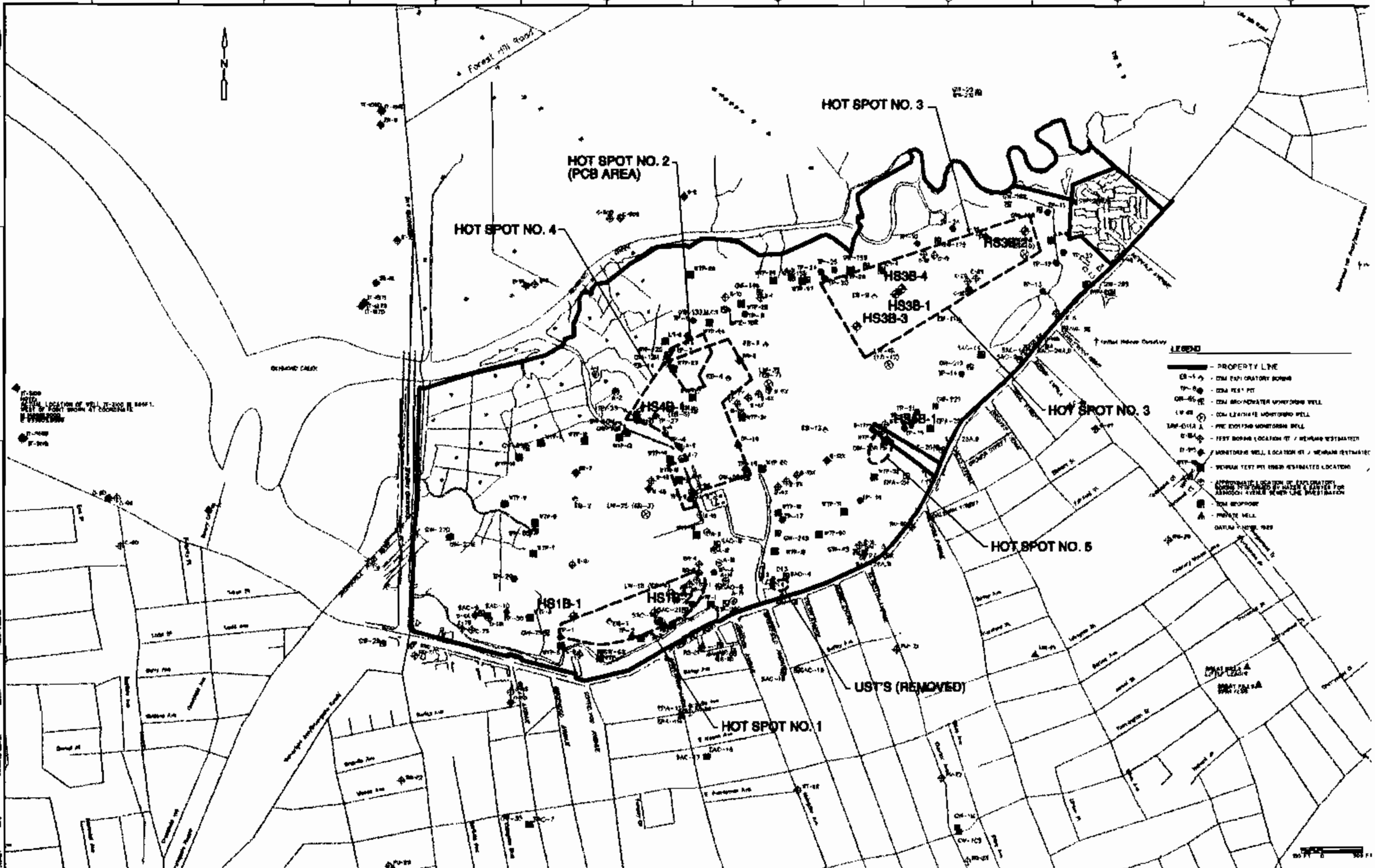

CDM Camp Dresser & McKee

NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

BROOKFIELD AVENUE LANDFILL
REMEDIATION PROJECT

OVERVIEW OF HOT SPOT DATA

DRAWING NO. ES-2

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- The plant community of the landfill provides potential moderate quality habitat for small birds and mammals, however, it does not constitute a major food resource for wildlife. Although some species produce nuts, berries, or fruits, they are quite scarce. No rare, threatened or endangered plants, and no plant species of special concern are known to occur onsite.

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Contaminant Fate and Transport

- Contaminant transport in the Upper Glacial aquifer is predominately limited to the site. These contaminants discharge to Richmond Creek. Because of the close proximity of the landfill to the creek, little contaminant attenuation occurs in the aquifer before discharge. The exceptions to this are semi-volatile contaminants, most metals, and PCBs which are strongly sorbed to the waste aquifer material limiting migration in the groundwater pathway.

- The potential for chemical transport to the deeper Cretaceous aquifer is likely limited because of the low downward leakage rate. Because of the relatively long travel path to this deeper

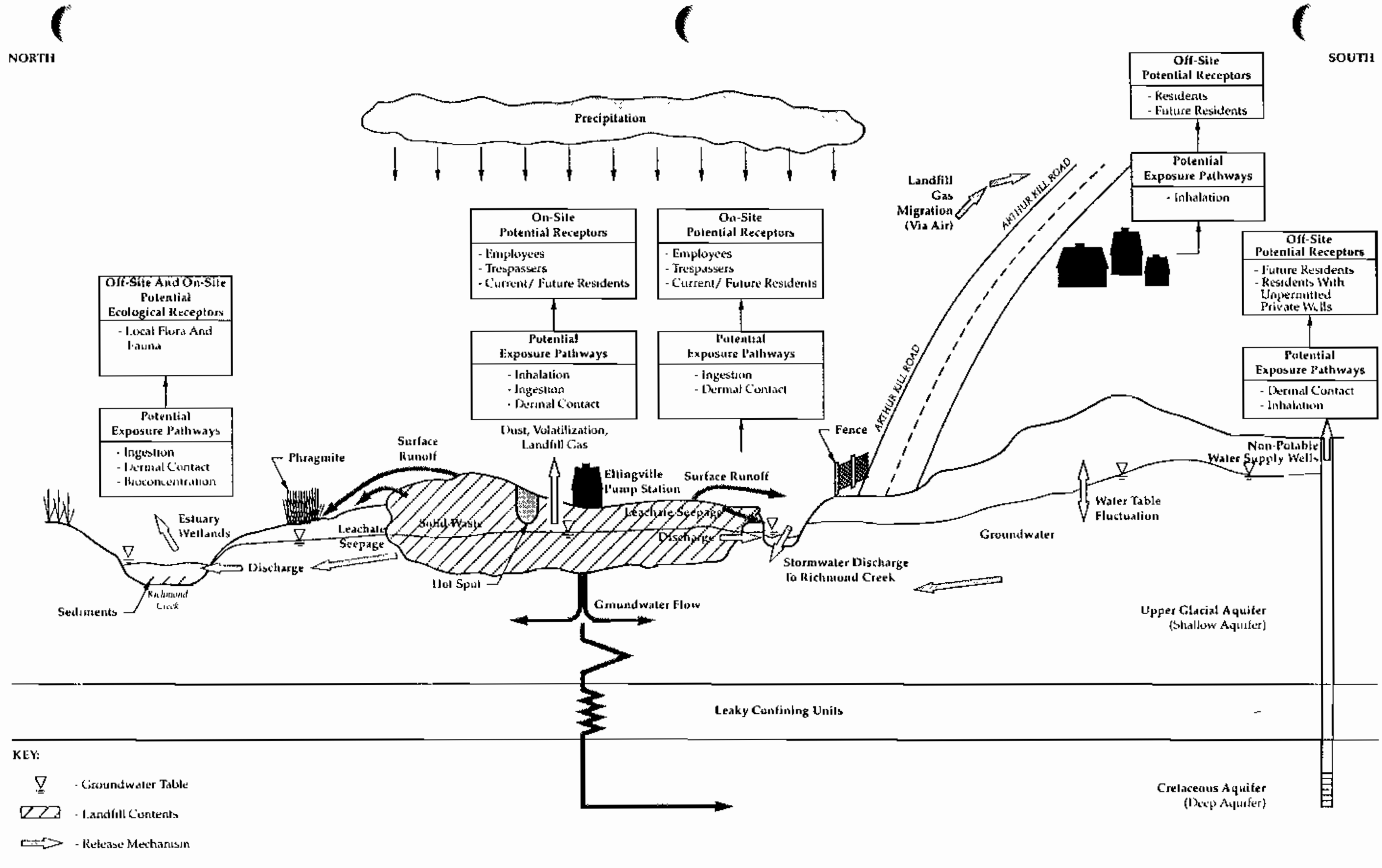

Figure ES-4
Conceptual Model of Contaminant Sources, Potential Migration Pathways, and Receptors
Brookfield Avenue Landfill Remediation Project

CDM Camp Dresser & McKee

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- Data from the six nearfield sediment and surface water sample locations does not implicate any particular area of the landfill as most likely contributing to the estimated ecological risk. Except for a group of pesticides detected from SW-4, the observed contaminants appeared consistently in a majority of the sediment and surface water samples, and at similar concentrations. The weight of evidence suggests that the entire landfill should be considered a source of area of contamination to Richmond Creek.

Identification of Data Gaps

The following data gaps were identified based on the results of the Remedial Investigation. The significance of these data gaps is also discussed.

- **Regional flow direction and pattern of the Cretaceous aquifer system.**

  The flow patterns in the Cretaceous aquifer are extremely complex. Even after collecting and evaluating significant quantities of Cretaceous data in the Brookfield area, the regional flow patterns remain somewhat uncertain because of a lack of regional data. Because the rate of leakage of Brookfield leachate to the Cretaceous aquifer is low, little leachate contamination was observed in the Cretaceous. This aquifer is not used for potable supply; thus, this gap is not an immediate concern and will not influence the remedy selection process.

- **Confirmation that landfill gas is not migrating in the soil south of Arthur Kill Road.**

  Several local areas near the south boundary of the site have periodically detected peak soil gas concentrations in excess of 100 percent LEL. While the location of these local areas suggest that the readings are not related to landfill gas, additional data needs to be collected to confirm this. This data gap is significant to the remedy design and will be addressed during the Feasibility Study.

- The NYSDEC's Division of Fish and Wildlife has requested resident biota sampling with tissue analysis for PCBs and mercury and additional sediment sampling in freshwater wetland AR-53 for PCB's, due to the close proximity of samples containing these contaminants to surface waters.

  This data gap has only minor significance to the remedy design since leachate generation from the landfill will be negligible after the components of the presumptive remedy (landfill cap, leachate collection and hydraulic control) are constructed. The NYCDEP will continue to work with the NYSDEC to develop a scope for this testing and carry out the biota sampling.

Recommendations

- The findings and conclusions of this Remedial Investigation are sufficient to proceed to the next phase of the remedy selection process, the feasibility study. It is recommended that the NYSDEC authorize the start of the feasibility study. The feasibility study should address institutional controls restricting well development in the area and future land uses for the site, containment of wastes, control of leachate discharge to surface waters and the Cretaceous aquifer, control of landfill gas emissions, and focused remediation of contamination source areas within the waste mound.

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List of Acronyms

Acronyms

AE	Acid Extractable Compound
AGC	Annual Guideline Concentration
AQUIRE	Aquatic Toxicity Information Retrieval Data Base
ASP	Analytical Services Protocol
ASTM	American Society of Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
ARAR	Applicable or Relevant and Appropriate Requirements
BN	Base/Neutral Compound
BRA	Baseline Risk Assessment
CAC	Citizens Advisory Committee
CDI	Chronic Daily Intake
CDM	Camp Dresser & McKee
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CGI	Combustible Gas Indicator
cm/s	centimeters per second
COC	Chemicals of Concern
CRDL	Contract-Required Detection Limit
CRP	Community Relations Plan

NTU	Nephelometric Turbidity Units
NYC	New York City
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYCDEP	New York City Department of Environmental Protection
NYCDOS	New York City Department of Sanitation
NYCDPR	New York City Department of Parks and Recreation
NYCDOH	New York City Department of Health
NYSDOH	New York State Department of Health
OVA	Organic Vapor Analyzer
PCB	Polychlorinated Biphenyl
PHA	Public Health Assessment
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
PVC	Polyvinylchloride
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RI/FS	Remedial Investigation/Feasibility Study
RAGS	Risk Assessment Guidance for Superfund
RfD	Reference Doses
ROD	Rock Quality Description
SAC	Scientific Advisory Committee
SCG	Standards, Criteria, Guidance

Section 1
Introduction

1.1 Background

The State of New York's Program to clean up inactive hazardous waste sites requires that a Remedial Investigation and Feasibility Study (RI/FS) be conducted to assist in the selection of a remedy for the site. This Remedial Investigation Report has been prepared for the New York City Department of Environmental Protection (NYCDEP) by Camp Dresser & McKee (CDM). The purpose of this report is to present the nature and extent of contamination at the Brookfield Avenue Landfill site in Staten Island, New York and to evaluate the risks from this contamination to human health and the environment. The Feasibility Study evaluates potential remedial options and recommends a remedy. This study will start at the completion of the Remedial Investigation report and is expected to be completed by the end of 1998.

Figure 1-1 delineates the steps taken to formulate a remedial strategy. This RI report represents the RI Reporting step in Figure 1-1. The approach has been a dynamic and flexible process tailored to the specific circumstances of the Brookfield Avenue landfill. As additional historical and background information on the area became available, it was continually evaluated and input into the RI/FS process. The RI/FS process is a step in a series of activities that are taken to remediate the site. First, the site was identified as a potential hazardous waste site by the New York State Department of Environmental Conservation (NYSDEC). Preliminary investigations were conducted to gather information about the history of the site, past disposal practices, potential responsible parties, and whether contamination is present. Based on that information, the site was classified by the NYSDEC according to the potential hazard to public health and the environment. The RI/FS is being performed to select a remedial strategy. After the strategy is agreed upon, design and implementation of the remedial action will take place.

Camp Dresser & McKee conducted the Remedial Investigation in accordance with the following documents:

- "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA", U.S. Environmental Protection Agency, October 1988; and

- "Conducting Remedial Investigations/Feasibility Studies for CERCLA Municipal Landfill Sites", U.S. Environmental Protection Agency, February 1991.

- RI/FS Work Plan; (CDM, August 30, 1993)

- Field Operations Plan; (CDM, August 30, 1993)

- Quality Assurance Project Plan (attached to the Field Operations Plan);

- Health and Safety Plan (attached to the Field Operations Plan); and

- Citizen Participation and Public Outreach Plan (CDM, August 30, 1993)

- Final Field Plan Addenda (CDM, March 1997)

1.2 Objectives of the Remedial Investigation

The objectives of this remedial investigation (RI) are to:

1. investigate the nature and extent of contamination for the Brookfield Avenue Landfill Site; and
2. assess the risks to human health and the environment.

The objectives of the RI do not include removing all scientific uncertainty, but rather to gather information sufficient to support an informed risk management decision regarding which remedy is determined to be most appropriate and cost effective.

1.3 Roles and Responsibilities

Various agencies, consultants, and community groups are participating in this investigation. Their roles and responsibilities are:

<u>City of New York</u> - Responsible Party, Respondent

<u>New York City Department of Environmental Protection</u> - City agency tasked to complete the remediation of the site.

<u>Camp Dresser & McKee</u> - Engineering Consultant retained by the NYCDEP to perform engineering services related to the remediation of this site.

<u>New York State Department of Environmental Conservation</u> - Enforcing environmental law applicable to the remediation of the site, oversees the implementation of engineering and remediation tasks, reviewing applications for financial assistance through the 1986 Environmental Quality Bond Act (EQBA).

<u>Brookfield Avenue Landfill Citizens Advisory Committee</u> - The CAC provides an ongoing forum for residents in the community to express concerns, reactions, and opinions to the NYCDEP, and allows the Department to respond in an appropriate and timely manner. The CAC allows those interested in the Brookfield Avenue Landfill RI/FS to participate in an advisory body that influences the project's scope, technical efforts, and the selection of remedial measures.

<u>Brookfield Avenue Landfill Science Advisory Committee</u> - As a result of community concerns regarding the credibility, comprehensiveness and validity of past studies of the Brookfield Avenue Landfill, the CAC organized a Science Advisory Committee comprised of four independent experts of various technical and scientific fields. This group provides expert peer-

This Phase II of field investigation activities was implemented from December 1996 through December 1997. The Phase II investigations were performed in accordance with the Field Plan Addenda (March 1997).

A series of technical workshops was held with the NYCDEP, NYSDEC, CAC/SAC, and CDM to discuss the interim findings as the study progressed. This RI workshop series started in July 1994 and was recently completed in March 1998. The consensus from workshops in October 1997 and February 1998, was to initiate a Phase III of field investigations to address two data gaps that emerged near the end of the study. The Phase III field investigations (i.e. 3 deep monitoring wells and additional sediment toxicity testing) are currently underway. The results of the Phase III investigations are not reported in this draft RI report. The Phase III results will be reported in the final RI report.

The NYCDEP has repeatedly demonstrated a commitment to working with the community and its scientific advisory committee to address their concerns that the investigation of the site be comprehensive and complete.

Funding for the remedy will come from a number of sources. The City of New York filed lawsuits against a number of major corporations whose hazardous wastes were allegedly dumped illegally at the Brookfield Avenue Landfill. Part of the funding for the Brookfield remedy will come from those settlements. Some funding for the remedy may be provided by the 1986 New York State Environmental Quality Bond Act (EQBA), where 1.1 billion dollars was set aside for corrective actions at hazardous waste sites across the state. Part of the funding will also come from the New York City budget.

1.5 Organization of the Report

This report is organized into seven sections and a series of appendices containing technical data and information. Section 1 includes a review of the framework that was used to implement this study. Section 2 includes a summary of background information used to formulate this study. Section 3 of this report contains descriptions of the objectives and methods of each investigation task. It also describes the physical characteristics of the study area. This includes the hydrogeology, the rate of leachate generation, the extent of waste and its characteristics, and an ecological assessment. Section 4 describes the nature and extent of contamination. Contaminant fate and transport is described in Section 5. Section 6 presents the risk assessment. Section 7 presents a summary of findings and recommendations.

Section 2
Site History and Background

The history of the site has been reconstructed from a variety of sources including:

- A review of approximately forty documents available in NYCDEP, NYCDOS, and NYSDEC files,
- The Stenographic Record of the Public Hearing on "Hazardous Waste Dumping in New York City",
- A review of over 150 Staten Island Advance articles dating back to 1975,
- Three public information meetings held on April 27, 1993, May 29, 1993 and July 22, 1993,
- Over 30 telephone interviews of residents,
- The distribution of over 500 questionnaires to residents (20% responded),
- Discussions with NYCDOS personnel and local officials,
- Review of historical aerial photographs from 1960, 1974, 1978, 1984, 1988 and 1991, and
- Door to door interviews of over 60 area residents.
- A NYCDEP review of the New York City Corporation Counsel files on Brookfield Avenue Landfill.
- A USEPA analysis of historical aerial photography of the Brookfield landfill.

2.1 Landfill Operations

2.1.1 Site Location

The Brookfield Avenue Landfill is located at 40°33'44" latitude and 74°09'38" longitude in Richmond County, Borough of Staten Island, City of New York, in the state of New York. The site, as shown in the Order on Consent, (see Appendix B) is bounded on the north by Richmond Creek, on the east by the Colonial Square Condominium properties on the south by Arthur Kill Road, and on the west by Richmond Avenue. The main gate to the site is on Arthur Kill Road.

Figure 2-1 is a site location map delineating site limits as defined in the 1992 Order on Consent. Residential areas can be found to the east, south and southwest of the landfill.

2.1.2 History of Operations

Landfill Operations

The New York City Department of Sanitation (NYCDOS) began operating the Brookfield Avenue Landfill in 1966 as a municipal solid waste disposal facility. During the 14 years of operation at the Brookfield Landfill, only about 130 acres of the site received refuse. The other 142 acres (272 acres total) served as a buffer zone between the landfill and the residences to the south and east. In 1978, the NYCDOS filed an application for approval to construct and operate a solid waste management facility at the Brookfield site, and for a variance to 6 NYCRR Part 360, but the application was never acted upon.

The facility served the 450,000 residents of Staten Island, accepting approximately 1,000 tons of refuse per day until its closure in 1980. Prior to closure, the landfill operated 24 hours per day, six days per week, with household refuse and construction debris delivered by the sanitation department and private garbage trucks. The loaded trucks were weighed on scales on site, their weight and the type of material they were hauling were recorded, then they were directed to an active area to deposit their load. The waste was dumped in lifts reaching up to 15 feet high and approximately 150 feet wide. Once a cell was completed, the lifts were compacted and cover material was applied. Access for public drop-off was permitted on the seventh day of the week. Residents were required to sign in and unload in an area specifically designated for public drop-off. Salvageable material suitable for recycling was removed by a private contractor. The salvage area was located on site in a separate fenced area so as not to interfere with daily operations.

The Brookfield Avenue Landfill has not accepted refuse since 1980, and was replaced by the Muldoon Avenue portion of the Fresh Kills Landfill complex. According to the NYCDOS, the Brookfield Landfill was closed in 1980 due to the proposed construction of a sewer main and pump station that was to go through the middle of the landfill and would seriously disrupt landfill operations. (Personal communication on May 20, 1993 with Phillip Gleason, NYCDOS). However, according to a Staten Island Advance article (May 1, 1979), in April 1979 then NYCDOS Commissioner Norman Steisel responded to a residential petition which complained of the increasing landfill garbage problems by stating that the landfill had almost reached capacity and would therefore close in 1980.

Industrial/Hazardous Waste Dumping

The Staten Island Advance (July 3, 1982) reported that in 1977 a chemical lake 100'x150'-200' existed 200' from Arthur Kill Road and that the chemical pond was, by the time of the report, buried 40' under the landfill. No further detail as to the composition of the waste is given. The exact location of the alleged chemical lake was not known prior to this RI study.

On May 6, 1982, a driver/dispatcher for the Hudson Oil Refining Company appearing before the Senate Committee on Crime testified that waste oil, sludges, metal plating wastes, lacquers and solvents were illegally disposed of at several New York City landfills, including Brookfield Avenue, between 1974 and 1980. The exact quantities and disposal locations of the wastes were not known. It was reported that volumes disposed of ranged from 11,000 to 55,000 gallons per week in 1974. In could be located in the NYCDOS records. Phase I closure included regrading, capping (24 inches of clay and topsoil), and seeding the area, and installing 10 passive vertical methane gas vents.

The first phase of the project started in October 1982 and was completed in 1984 at a cost of 2.8 million dollars. Additionally, the truck scale was demolished in the fall of 1981. A passive methane venting trench was constructed in 1984. Since then, only basic maintenance has occurred at the site.

The Phase II Closure Design began in December 1981 with a Request for Proposals. Wehran Engineering, a Consulting Engineering firm, won this bid and signed a contract with New York City on June 17, 1982. Wehran's first milestone was a geological site investigation, which it reported in August 1983. This report classified all hydrogeologic conditions at the site.

Wehran also produced several Phase II closure reports in Fall 1983. A Regulatory Requirements Report surveyed the relevant environmental laws and proposed entering into a Consent Order with NYSDEC to expedite the closure. In November, a hydrogeologic report listing the results from 32 test pit excavations was released. This included classification and permeability measurements for the strata at the site. Wehran provided several cost estimates for the final closure, predicting a cost in the range of $6 to $8 million. A Preliminary Engineering Report recommended 7 options for closing the site, but a clay cap final cover was seen as the most efficient abatement method for the site. Finally, a Preliminary Technical Specification for the site described point-by-point construction procedures for grading, ventilating, capping, and covering the Phase II area. These plans were never implemented.

The last NYCDOS field investigations of the Brookfield Landfill were the Wehran Fourth Quarterly Sampling Report, October, 1984 and York Research's Summary Test Report for Air Quality and Emissions Monitoring Program at Brookfield from November 1983 to June 1985. Most actions, according to the NYSDEC chronology of events pertaining to Brookfield Landfill from December 1985 to March 1992, relate to landfill closure plans, the methane gas venting system extension, and routine field inspections.

The routine field inspections by the NYSDEC revealed a number of violations and concerns including:

- Construction and demolition waste deposited in the landfill and the extension of the methane gas venting system.
- Drum removal and site maintenance and security deficiencies.
- Ponding of surface water in the vicinity of the pumping station and high grass/weeds all over the landfill and in the methane trench which may restrict passive venting of the gas.
- Exposed solid waste in the vicinity of a depression near the center of the landfill to the north and east of the main gate.

water quality and is almost entirely supplied by gravity. Water is conveyed to Staten Island from reservoirs of the Catskill-Delaware System through several aqueducts and City Water Tunnel No. 2.

Connecting to Tunnel No. 2 in Brooklyn is the 10-foot diameter, 5-mile long Richmond Tunnel, which was completed in 1970 and carries water 900 feet beneath Upper New York Bay to Staten Island. The Richmond Tunnel, Richmond Distribution Chamber, Richmond Aqueduct, and underground Silver Lake Tanks were designed to improve the water supply to Staten Island. The two underground storage tanks are among the world's largest, having a combined capacity of 100 million gallons, and replaced the Silver Lake Reservoir (now Silver Lake).

According to Soren (1988), groundwater has not been used for public supply since September 1970. Before 1970, New York City generally pumped less than 5 million gallons per day (Mgal/d) to supplement the surface-water supply from upstate New York. Pumpage reached as much as 5 Mgal/d only during drought periods that reduced the supply from upstate reservoirs. Maximum pumpage was limited to 5 Mgal/d because higher rates induced significant saline groundwater infiltration that contaminated the supply.

Nevertheless, a number of private wells have been installed by homeowners and commercial establishments for lawn irrigation, automobile washing, filling of swimming pools, and similar uses. Input from the community has identified several of these wells near the Brookfield site. A review of NYCDOH and NYSDEC records, indicates that only three private wells are within 3000 ft of the site. Only one of these wells has a permit.

The Brookfield study area is serviced by the Oakwood Beach WWTP and collection system.

The Oakwood Beach WPCP is located in the Borough of Staten Island on the shore of Raritan Bay, east of Great Kills Harbor. It serves an area of approximately 22,500 acres in the southeastern part of Staten Island, including the communities of Fresh Kills, Totenville, Eltingville, Oakwood Beach West, and Oakwood Beach East. The treatment facilities provided at Oakwood beach WPCP have capacity for an average annual wastewater flow of 40 mgd. Available operating data indicates the plant currently treats 30 mgd of flow.

Three interceptors converge at the Eltingville Pump Station which is located in the center of the Brookfield site. Two of these interceptors are constructed beneath waste disposal areas. The wastewater system interceptors and WPCPs for Staten Island are shown in Figure 2-4.

2.2.6 Demographics

Low density residential land uses predominate in the Oakwood Beach WPCP drainage area. Seventy five percent of the total land area consists of 1- and 2- family houses. Condominiums occupy 7.5 percent of the drainage area. There were no old-law tenements recorded and very few elevator buildings. Walkup apartment buildings occupy only 0.5 percent of the land area.

The heaviest concentration of commercial land use is located along Hylan Boulevard with virtually all businesses directed towards residential services. Industry is scarce in this area, occupying only 76 lots in the drainage area.

Vacant land, concentrated along the west side of Staten Island, occupies 12.7 percent of the total area and is being developed rapidly. Gateway National Park, Blue Heron Pond Park, Wolfe's Pond Park, and La Tourette Park are among the largest parks in the drainage area. These, along with several cemeteries, provide much open space. Extensive wetland areas are located throughout the drainage area. Fresh Kills Creek and Richmond Creek are surrounded with wetlands that provide critical habitats for shore birds and other wildlife.

The population in the area is expected to increase over the next 25 years. The projected population figures for the Oakwood Beach drainage area are as follows:

PROJECTED POPULATION
OAKWOOD BEACH WPCP DRAINAGE AREA

Year	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Population (thousands)	204	211	214	222	231	246	251	255	257	259
SOURCE: Population Figures are as developed by Allee King Rosen and Fleming, Inc. (AKRF) as part of Sludge Management Task 26-WPCP Flows and Projections, working paper no. 1: Population and Employment Projections, July 1991										

2.3 History of Contamination

Existing environmental studies of the site were performed prior to 1985. One exception to this is recent surface water quality data collected as part of the neighboring Fresh Kills Landfill studies. These data were collected in 1984 and 1990. Approximately 56 monitoring wells and soil borings were installed onsite as part of past investigations, their locations are illustrated in Figure 2-5. A site reconnaissance visits by the project team located only 21 of these monitoring wells. Thirteen of the wells were seriously degraded and damaged, 7 were in questionable, unsecure condition, useable as piezometers, and one was useable for groundwater sampling.

A review of these data is useful in developing a conceptual model of the site. While useful for study planning, these data are old and were collected using older, less representative techniques than are used today and therefore do not provide a current diagnosis of the site. In addition, the data are not distributed in a manner that characterize the entire site.

A summary of contaminants detected at the site is found in Table 2-1. Detailed descriptions of sample locations, methods, and date of sampling can be found in the referenced historical documents.

2.3.1 Groundwater

In 1980, the study of six NYCDOS landfill disposal facilities was conducted by Parsons Brinkerhoff-Cosulich and Geraghty & Miller, Inc. for NYCDOS. Nine liquid samples were taken for the Brookfield Avenue landfill: one leachate, five groundwater, and three surface water. The

Table 2-1

Observed Historic Contaminant Concentration Ranges

Brookfield Avenue Landfill Remediation Project

Contaminant	***Groundwater*** ***(µg/l)***	***Surface Water*** ***(µg/l)***	***Ambient Air*** ***(µg/m³)***
Arsenic	ND	ND	0.004-0.257
Barium	200-1,900	ND	NR
Cadmium	ND-7	ND	ND
Calcium	36,000-490,000	180,000-310,000	NR
Chromium	ND-20	ND	ND
Copper	ND	ND-40	NR
Iron	1,000-546,000	480-4,800	NR
Lead	ND-70	ND-85	0.272-0.814
Manganese	390-13,000	160-690	NR
Mercury	ND-32	ND-0.6	0.0003-0.0013
Nickel	20-220	ND-20	ND
Selenium	NR	NR	0.045-0.0996
Silver	ND	ND-30	ND
Zinc	60-2,790	ND-50	0.195-0.351
Cyanide	ND-40	ND-10	NR
Fluoride	110-560	330-560	NR
Detergent (NBAS)	ND-61,000	ND-230	NR
TKN	3,700-434,000	2,200-18,000	NR
Nitrate (NO_3-N)	ND-100	100-2,700	NR
TDS	64,000-18,100,000	264,000-24,605,000	NR
Phenols	ND-18	ND-6	ND
Sodium	10,700-5,280,000	900,000-6,200,000	NR
Ammonia (NH_3)	170-5,490,000	1,400-14,300	20.2-93
Potassium	2,800-305,000	90,000-240,000	NR
Chloride	21,000-5,300,000	42,000-11,750,000	NR
Methylene Chloride	ND-10	ND-14	ND-161
Chlorobenzene	17-50	ND	NR

concentrations of eleven constituents in the groundwater samples exceeded NYSDEC Class GA groundwater standards (potable standards). Even though the local community is connected to the NYC Water Supply System for potable water (see Section 2.2.5), potable water standards are used for comparison because the local aquifer is classified by the State as a potential water supply. These constituents include arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, and zinc. The results of analyses for trace organic substances including PCB's and pesticides were negative (Geraghty & Miller 1980).

Additional leachate and groundwater samples were collected and analyzed in 1982 as part of the Parsons Brinckerhoff-Cosulich investigation of indicator pollutant levels made for the NYCDOS. Samples were analyzed for volatile organic compounds, PCBs, phenols, cyanide, and a number of heavy metals.

Leachate samples indicated that cadmium, chromium, lead and methylene chloride were found in concentrations exceeding NY State Class GA (potable) Groundwater Standards. Ethyl benzene and toluene were identified but found to be within acceptable limits. PCBs were undetectable.

Groundwater samples were collected from 18 designated on-site wells and 11 designated off-site wells located in deep/shallow clusters. Three of the wells were installed in 1980 while the remaining wells were installed in 1982. For those wells located around the periphery of the landfill and off-site, the limited available boring logs indicated that the wells extended between about 24 feet and 35 feet below ground surface. For the comparison of heavy metals, results from filtered samples were used. Lead, cadmium, chromium, mercury, iron, manganese, sulfates, and cyanide were found in concentrations exceeding NY State Class GA (potable) Groundwater Standards in many on-site wells. Except for one well, the only parameters which exceeded the standards in off-site wells were phenols, iron and manganese. Volatile halogenated organics, specifically, ethylene chloride, 1,1-dichloroethane, 1,1,2-trifluoroethane(freon), and ethylene dichloride were found in several wells at concentrations less than 5 ug/l. One well, screened in the east refuse mound, has shown repeated presence of benzene, toluene and xylene at concentrations less than 20 ug/l. Another well in the same cluster, but screened approximately 25 feet below the bottom of the refuse and below a 2-foot layer of a clayey-silty soil, did not show the presence of benzene, toluene, or xylene (Parsons Brinckerhoff-Cosulich, 1982). As with results of leachate sampling, PCBs were below detectable limits.

Surface water, groundwater, and leachate samples were collected, analyzed, and compared with historical data in a 1984 Phase II Interpretation Report prepared for NYCDOS (Wehran Engineering - H2M, 1984). The samples were analyzed for volatile organic compounds, polychlorinated biphenyls (PCBs), phenols, cyanide, and heavy metals.

Landfill leachate was sampled from three wells BR-5, B-5X and B-8X screened in Brookfield's upper unconfined aquifer. These wells were sampled because Grand Jury testimony (1982) indicated that hazardous waste dumping may have occurred in these areas and so they would provide a "worst case" leachate analysis.

Well E-9 demonstrated relatively clean, fresh water in the upper aquifer adjacent to Brookfield's southern boundary. Well D-14, however, is within 100 feet of the tidal stream and in July 1982, it

2.3.3 Landfill Gas

Landfill gas is produced through the decomposition of solid waste. Historic data for landfills in the northeast indicate that the peak gas production phase for landfills begins between three and five years after cessation of filling activities, and declines gradually over a period of tens of years. (Gas production rates are reduced by about 30% from peak after 10 years, 50% after 20 years, and 75% after 30 years).

Landfill gas typically exhibits the tendency to preferentially move horizontally. A general industry rule of thumb used when working with landfill gas is that the gas moves eight feet horizontally for every one existing vertical foot of uncapped solid waste. Using this approximation, the potential extent of landfill gas influence from the Brookfield Avenue Landfill is estimated at 350 feet from the edge of the fill mass.

Typically in a municipal landfill the major components of landfill gas are methane and carbon dioxide, with trace amounts of other gases, such as hydrogen sulfide. Hydrogen sulfide has a very strong odor, detectable to humans at extremely low levels. Methane is typically used as an indicator of landfill gas. Background levels of methane in air are typically in the range of 3 to 5 parts per million (ppm). Background levels of methane in soils vary greatly, with values of 10 to 20 ppm typically used. However, marsh soils, like those found at the Brookfield Avenue Landfill site, are different, as the decomposition of organic matter in the marsh environment also releases methane and hydrogen sulfide.

Weather has an impact on landfill gas emissions. Barometric changes impact the emission rates of gas, with low pressure systems typically associated with higher emission rates and high pressure systems associated with low emission rates. This effect is referred to as barometric pumping. Wet weather and freezing and thawing of the ground can also limit emissions and can affect the potential flow paths of migrating gas by pushing gases out from the landfill mass in a lateral direction.

Historically, gas and odors have been a concern in the Brookfield Avenue Landfill area. In 1983, a NYCDOS consultant began a monitoring program in which test pits and piezometers were monitored for soil gas. From the data obtained, the consultant concluded that the gas was being released through the landfill surface, and that no offsite landfill gas migration was occurring.

In 1984, a NYCDOS consultant began weekly monitoring of combustible gas levels along Arthur Kill Road. From reviewing the available documents, the reasons for conducting the monitoring program are unknown and the readings obtained are not interpreted or explained. A summation of the program is as follows (historical data is attached):

- The program began in mid-July 1984 and ended in January 1985.
- Levels of combustible gas in excess of the lower explosive limit for methane were detected from July through September, 1984.
- A passive vent interceptor trench was constructed by NYCDOS in September, 1984, extending in three segments from Brookfield Avenue to Doane Avenue.

2.3.5 Health Survey

During the 1982 sewer line construction through the landfill, there were numerous complaints from residents of the neighboring community of intense foul odors and complaints of increased health problems (e.g., nausea, retching, vomiting, burning eyes, and sore throats as well as respiratory problems).

Also during 1982, there was public disclosure of large scale illegal disposal of toxic wastes at this landfill having taken place over the course of several years. In response to the health concerns, the NYC Health Department conducted a health survey for the Brookfield Avenue Landfill area, (Schultz, undated). The study concluded that the only community exposure which had been documented was odor. Odor is a subjective response to low doses of complex mixtures of volatile chemicals which are perceived by people in low concentrations, even as low as parts per billion.

The investigation stated that people in the community who live closer to the landfill had a higher rate of medical utilization than those living at greater distances. The majority of illnesses encountered were those of the upper portion of the respiratory tract. Headache and nausea were also experienced among those affected residents living closest to the landfill. The excess illness in the study population was compatible with an intermittent exposure to strong odorants and irritants emanating from the landfill and the NYCDOH indicated the pattern of illness seen in the investigation suggested an acute noxious exposure rather than a toxic one.

Using the same NYCDOH data, Warren (1985) indicated that more adverse health impacts occurred in the study area adjacent to the Brookfield Landfill when compared to the control area, with children and the elderly experiencing the greatest reported adverse health effects. Observed health effects indicated that eye, ear, nose, and throat conditions as well as sinusitis, asthma, bronchitis, and allergies were significantly more numerous for the study group than the control. The study also indicated that those members of the control group who spent a lot of time near the landfill (at work, at school, etc.) experienced more adverse health effects than those who did not spend time near the landfill.

In conjunction with her constituents, former U.S. Congresswoman Susan Molinari petitioned the Agency for Toxic Substances and Disease Registry (ATSDR) to perform a public health assessment (PHA) of the Fresh Kills Landfill and the Brookfield Avenue Landfill. A PHA is an evaluation of pertinent environmental data, health outcome data, and community concerns related to a waste site. Aware of community concerns about air emissions from the landfills, ATSDR has decided to produce individual health consultations on air quality data as soon as possible after the data are available to ATSDR. A health consultation primarily responds to a specific questions. The consultations will become components of the future PHA, and any comments or additional data received in response to this consultation will be addressed in subsequent reports.

The Fresh Kills Landfill Health Consultation (ATSDR, 1998) was released in January 20, 1998. The Brookfield Avenue Landfill ATSDR Health Consultation is scheduled for release in the substances illegally dumped at the site. As of July 29, 1992, New York City was awarded 55 million dollars in response action costs and 7 million dollars in natural resource damages for a total of 62 million dollars (NYC Press Release, July 29, 1992). This press release is found in Appendix C.

2.3.7 Corrective Measures Taken to Date

In 1982, an improvement program was undertaken for the 38 acre easterly fill area at the Brookfield Avenue Landfill. The area was regraded, a final soil and clay cover applied, and the cover was seeded. Methane vents were installed along the southern periphery of this area, and fencing was erected.

In 1984, a passive gas vent system to control methane migration was installed along Arthur Kill Road in the vicinity of Colon Avenue and Brookfield Avenue. The system, as designed, consisted of a long trench extending below the water table filled with gravel and containing a perforated pipe. As constructed, the system consisted of three shorter, non-continuous trenches, only one of which contained a perforated pipe. In 1986, the 200 foot long trench along Arthur Kill Road had been extended by 325 feet to further inhibit gas migration.

In March 1995, the NYCDEP retained a subcontractor to remove two 550-gallon diesel fuel tanks near the entrance of the facility. This work was performed under the supervision of the NYSDEC. The closure report for the removal of these tanks is found in Appendix P.

2.4 Starting Site Conceptual Model

Based on review of the waste disposal history, data from past investigations, and the physical setting of the site, CDM developed a conceptual model of the potential contaminant migration pathways in order to design a comprehensive Remedial Investigation (RI). This model was updated and revised throughout the RI process to reflect new data and findings. Figure 2-6 is a graphic representative of CDM's initial conceptual model for the site.

Initially, potential contamination migration pathways at the site included two major pathways; air, and/or water and a number of subpathways. These pathways are discussed individually below.

Contamination Migration via the Air Pathway

Volatile emissions or wind transport of soil particles may present potential contaminant migration pathways from the landfill. The contaminants are potentially subject to inhalation by onsite and offsite humans and fauna. Dust particles transported by the wind may also subject receptors to dermal contact and bio-uptake from the soil or sediment.

The migration of landfill gases through vadose zone soils was another potential pathway. Conduits of coarse soils such as fill and trenching backfill for utilities have a high potential for gas migration from the landfill to residential areas or city facilities.

Contamination Migration via the Water Pathway

Potential migration via the water pathway would take many forms: soil erosion; runoff to surface water; runoff that infiltrates to groundwater; groundwater, and surface water. The historical (pre-RI) data suggested that the primary pathways are groundwater and surface water. Because the site in its existing condition is generally well vegetated with mild slopes, soil erosion and runoff were believed to be pathways of secondary importance.

During high volume and/or long duration rainfall events, surface ponding, runoff, and soil erosion may occur, predominantly on the side slope areas. Contaminated soils and runoff could be transported via the site's drainage features to depressions in the landfill or discharge to surface waters.

Surface water may also infiltrate the landfill as a result of tidal fluctuations or floods, become leachate, and enter the groundwater system. Groundwater from beneath the landfill may carry contaminants into Richmond Creek or into aquifers beneath the landfill.

Lateral migration of leachate in the upper, unconfined water bearing zone northward in the direction of Richmond Creek was believed to be the primary water pathway. Lateral migration southward toward residential areas was considered unlikely because of the regional flow direction data, but was identified as a potential secondary pathway. Because the topography of the residential area reaches elevations greater than the landfill, it was estimated that the groundwater flow is predominantly north toward the creek. This upper unconfined zone was thought to be generally separated from the underlying unconfined and semi-confined Glacial aquifer by tidal marsh deposits. However, these tidal marsh deposits were believed to be discontinuous across the entire site and portions may have been excavated during landfill and sewer main construction. These discontinuities in the salt marsh deposits would offer limited vertical conduits for downward flow to the underlying Glacial aquifer. The sanitary sewer main and the storm sewer and their associated bedding materials that bisect the site were also considered potential preferential pathways for migration of contaminated groundwater/leachate offsite.

Groundwater flow to the deeper confined Cretaceous aquifer was thought to be in a southerly direction based on data from the Fresh Kills Landfill hydrogeologic investigation. However, it was not believed to be a significant pathway of contamination because of the extensive confining units separating the Upper Glacial and Cretaceous aquifers.

Surface waters of consideration included both tidal and non-tidal waterbodies. Surface waters receiving contaminated groundwater, sediment or runoff were considered to have the potential of distributing the contamination throughout neighboring wetlands, the tidal Richmond Creek and potentially Fresh Kills and Arthur Kill.

Based on our review of documents concerning illegal dumping, the large quantities of liquid hazardous waste reportedly dumped into the landfill have likely undergone a number of fates:

Section 3
Study Area Investigations

This section of the report contains descriptions of the objectives and methods of each investigation task. It also describes the physical characteristics of the study area. This includes the hydrogeology, the rate of leachate generation, the extent of waste and its characteristics and an ecological assessment.

3.1 Summary of Phases of Investigation

The field investigations were conducted in phases.

- The original workplan was approved in August 1993.
- Phase I field work was performed from December 1993 through June 1994. This included:

  - 23 soil borings
  - 20 test pits
  - 16 surface soil samples
  - 36 monitoring wells (1 round of sampling)
  - 5 surface water/sediment samples (1 round of sampling)
  - 10 leachate samples
  - 3 rounds of landfill gas emission and ambient air samples
  - residential tap water testing
  - basement screening for landfill gas
  - perimeter soil gas monitoring
  - 5 sediment toxicity tests

- A Final Field Investigation Plan Addenda was issued in March 1997.

- The Phase II field work was performed from December 1996 through December 1997. This included:

  - second round of groundwater, surface water, sediment, and leachate sampling
  - a fourth round of landfill gas emission and ambient air sampling
  - additional perimeter soil gas monitoring
  - soil gas surveys of three hot spots
  - eight hot spot borings
  - 36 soil samples
  - 12 test pits
  - installation of 21 monitoring wells
  - radiation screening of 400 soil samples
  - collection of 4 landfill gas samples

- Phase III Field work is currently underway. These activities include:

  - three deep monitoring wells
  - additional acute, chronic, and bioaccumulation studies to determine sediment toxicity.

determined with one test pit, necessitating the need for additional test pits during Phase II field activities.

For Phase I test pitting, one grab sample of waste/soil from the apparently most contaminated area was collected for laboratory analysis. Lab samples were not collected during Phase II test pitting, because sufficient chemical data was generated during Phase I.

3.2.3 Results and Conclusions

The locations of test pits and exploratory borings are shown in Drawing No. 2 (Appendix A). Drawing No. 1 also shows the extent of solid waste (that greater than one foot thick) as determined by the historical aerial photographs, the test pitting, and exploratory borings. Boring and test pit logs are found in Appendix G.

The Brookfield Avenue Landfill site contains 132 acres of solid waste buried on the 272 acre site. It is estimated that 5.11 million yd^3 of waste were disposed of at this landfill. Assuming a compacted specific weight of the solid waste of 1,000 lb/yd^3, this equates to 2.5 million tons of waste.

The vast majority of the waste mass can be characterized as municipal/household solid waste with localized areas of construction and demolition (C & D) and metal areas. It is estimated that C&D material only accounts for about 21,000 yd^3. Industrial wastes were reportedly disposed of on and within the landfill as free liquids. No industrial waste container (i.e., drums) were located during this investigation.

The geotechnical characteristics of the waste material and cover material are discussed in Section 3.10 of this report.

3.3 Determination of Off-Site Dumping

During the preparation of the work plan for this remedial investigation, several community members offered the possibility that industrial waste may have also been disposed of in the residential area. This scenario/concept is summarized as follows:

Court testimony and statements by residents suggest that much of the industrial/hazardous waste disposal at the Brookfield Avenue Landfill occurred at night or after normal operational hours. For an unknown period, the demand for industrial waste disposal at Brookfield exceeded the rate the trucks were allowed on-site. Residents report that lines would form outside the gate waiting to dump at Brookfield. Residents reported that when the lines were too long, that these trucks would dump in a variety of residential construction areas.

Interviews with residents (door to door surveys and discussion at public information meetings on this project) and Staten Island Advance articles allege that illegal dumping took place beyond the boundaries of the landfill. Residents in the area have made claims that liquid waste dumping occurred at nearby construction sites when the Brookfield Avenue Landfill was in operation. Aerial photographs of the area from 1960, 1974, 1978, and 1991 were reviewed to identify any of these construction areas south of the Brookfield Avenue Landfill. Six construction sites and/or

The hydrogeologic characterization was performed in Phase I, Phase II and Phase III of field activities. Phase I activities focused on the shallow aquifer and performed some testing of the deeper cretaceous aquifers to verify and supplement what was already known about them. Existing studies indicated that the potential for leachate leakage to the deep aquifer was very low. Based on stratigraphic information obtained during the Phase I field investigation and concerns of the Scientific Advisory Committee, the Phase II and III investigations focused on the deeper aquifer and the confining unit that separates the shallow and deep aquifer.

3.4.1 Objectives

The objectives of the hydrogeologic characterization were to:

- Further define the distribution of key hydrogeologic units and their hydraulic conductivities,
- Define the groundwater flowfield and identify preferred flowpaths,
- Determine the size and configuration of the hydraulic mound in the landfill and further define how much solid waste is saturated,
- Determine the surface water influence on the groundwater system and flows in and out of the landfill,
- Define the extent of contamination, determine if contamination has reached or has the potential to reach deeper Cretaceous aquifers,
- Identify groundwater discharge areas and potential receptors,
- Generate data to evaluate remediation technologies during the feasibility study.

3.4.2 Investigation Procedures

The hydrogeologic characterization focused on the three main aquifer systems found at Brookfield Avenue Landfill. These include the (1) Recent/Shallow Glacial, (2) Deep Glacial/Reworked Cretaceous and the (3) Cretaceous aquifer system. To accomplish the objectives of the hydrogeologic characterization the following procedures were used.

- Monitoring Wells: During Phase I of field work, wells were installed primarily in the shallow aquifer system. During Phase II of the Remedial Investigation the investigation focused on the Cretaceous aquifer and potential impacts to this aquifer.
- Geoprobes: Used during Phase II to investigate potential hot spot areas identified during Phase I of the remedial investigation.
- Permeability Testing: Established hydraulic conductivities for the various geologic units through the use of monitoring well slug tests, Shelby tube soil samples, and laboratory analysis of soil properties.

Ta... 3-1

Monitoring Well Construction Data Summary

Brookfield Avenue Landfill Remediation Investigation, Staten Island, New York

Well ID No.	Material	Diam (in)	Top of Casing Elevation (ft MSL)	Surface Elevation (ft MSL)	Screened Interval (ft MSL)	Screened Interval (ft BLG)	Date Installed	Study	Hydrogeologic Unit	Current Status
MW-1	PVC	4.00	17.63	11.70	-3.3 to -13.3	15 to 25	09/16/83	E	Glacial Till / Glaciolacustrine Clay Silt (1f)	Located,Usable
MW-2	PVC	4.00	ND	3.60	-13.9 to -23.9	17.5 to 27.5	09/20/83	E	ND	Not Located
MW-2A	PVC	4.00	ND	3.90	-1.1 to -6.1	5 to 10	09/20/83	E	ND	Not Located
MW-3					WELL NOT	INSTALLED		E	ND	
MW-4	PVC	4.00	ND	5.20	-9.8 to -14.8	15 to 20	09/21/83	E	ND	Not Located
MW-4A	PVC	4.00	ND	5.00	0.0 to -5.0	5 to 10	09/22/83	E	ND	Not Located
BR-2	PVC	1.25	ND	18.20	-3.3 to -8.3	21.5 to 26.5	05/03/83	D	Glacial Till / Glaciolacustrine Clay Silt (1f)	Damaged
BR-3	PVC	1.25	ND	17.10	-1.9 to -6.9	19 to 24	05/09/83	D	Fill / Recent Silt and Clay (1a/1c)	Damaged
BR-4	PVC	1.25	ND	15.30	-3.7 to -8.7	19 to 24	05/10/83	D	Fill Material (1a)	Damaged
BR-5	PVC	1.25	ND	16.10	-1.4 to -8.4	17.5 to 24.5	05/10/83	D	Fill / Shallow Glacial Sand (1a/1e)	Damaged
BR-6	PVC	1.25	ND	26.80	-1.2 to -6.2	28 to 33	05/11/83	D	Fill Material (1a)	Damaged
BR-7	PVC	1.25	ND	30 30	-3 7 to -8.7	34 to 39	05/17/83	D	Recent Silt and Clay / Glacial Till (1c/1h)	Not Located
B-4X	PVC	1.25	ND	28.50	-5.5 to -10.5	34 to 39	04/25/83	D	Glacial Till / Glaciolacustrine Clay Silt (1f)	Damaged
B-5X	PVC	1.25	ND	27.70	-6.3 to -11.3	34 to 39	04/26/83	D	Glacial Till / Glaciolacustrine Clay Silt (1f)	Damaged
B-6X	PVC	1.25	ND	27.30	-0.7 to -5.7	28 to 33	04/27/83	D	Fill Material (1a)	Damaged
B-7X	PVC	1.25	ND	23.10	-9.9 to -14.9	33 to 38	04/27/83	D	Glacial Till / Glaciolacustrine Clay Silt (1f)	Damaged
B-9X	PVC	1.25	ND	19.60	-0.4 to -5.4	20 to 25	05/03/83	D	Fill Material (1a)	Not Located
B-10X	PVC	1.25	ND	22.60	0.6 to -4.4	22 to 27	05/04/83	D	Fill Material (1a)	Not Located
B-11X	PVC	1.25	ND	31.20	-5.8 to -10.8	37 to 42	05/09/83	D	Glacial Till / Glaciolacustrine Clay Silt (1f)	Damaged
B-12X	PVC	1.25	ND	34.00	-2.0 to -6.0	36 to 40	05/11/83	D	Fill Material (1a)	Not Located
B-13X	PVC	1.25	ND	22.20	-1.8 to -6.8	24 to 29	05/17/83	D	Fill Material (1a)	Not Located
BR-1	PVC	1.25	ND	15.90	-6.1 to -11.1	22 to 27	05/03/83	C	Fill Material (1a)	Damaged
B-3X	PVC	1.25	ND	23.00	-11.0 to -16.0	34 to 39	04/22/83	C	Recent Sand (1d)	Damaged
B-8X	PVC	1.25	ND	16.00	1.0 to -4.0	15 to 20	05/03/83	C	Fill Material/Recent Silt and Clay (1a/1c)	Not Located
B-13X	PVC	1.25	ND	22.20	-37.8 to -42.8	60 to 65	05/19/83	C	Deep Glacial Sand (1g)	Not Located
D-11A	PVC	4.00	ND	6.30 RD	-72.7 to -100.7	79 to 107	02/17/82	B	Very Fine Sand, Light Gray (4a)	Not Located
D-11B	PVC	4.00	ND	6.30 RD	-18.7 to -43.7	25 to 50	02/22/82	B	ND	Not Located
D-12	PVC	4.00	14.08	9.10 RD	-131.9 to -157.9	141 to 167	02/18/82	B	Fine to Med. Sand, Light Gray (5)	Located,Unsecure
D-13	PVC	4.00	14.10	9.10 RD	-101.9 to -110.9	111 to 120	02/23/82	B	Very Fine Sand, Light Gray (4a)	Located, Unsecure
D-14	PVC	4.00	14.14	9.10 RD	4.1 to -65.9	5 to 75	02/25/82	B	Glacial Till with Sand (1h)	Located, Unsecure
D-15A	PVC	4.00	24.68	19.60 RD	-105.4 to -138.4	125 to 158	03/12/82	B	Very Fine Sand w/Clay, Gray (4/4a)	Located
D-15B	PVC	1.25	24.03	19.60 RD	-17.4 to -49.4	37 to 69	03/12/82	B	Glacial Till with Sand / Reworked (1h/1i)	Located
D-16	PVC	4.00	ND	2.10 RD	-54.4 to -86.4	56.5 to 88.5	03/16/82	B	Glacial Till with Sand (1h)	Not Located
C-1D	PVC	1.25	ND	2.00 RD	-10.0 to -20.0	12 to 22	01/13/82	B	Glacial Till / Glaciolacustrine Clay Silt (1f)	Located, Unuseable
C-1S	PVC	1.25	ND	2.00 RD	-8.0 to -13.0	10 to 15	01/13/82	B	Recent Sand (1d)	Located, Unuseable
C-2D	PVC	1.25	ND	34.10 RD	-25.9 to -30.9	60 to 65	11/09/81	B	Glacial Till / Glaciolacustrine Clay Silt (1f)	Located, Unuseable

Table 3-1
Monitoring Well Construction Data Summary
Brookfield Avenue Landfill Remediation Investigation, Staten Island, New York

Well ID No.	Material	Diam (in)	Top of Casing Elevation (ft MSL)	Surface Elevation (ft MSL)	Screened Interval (ft MSL)			Screened Interval (ft BLG)			Date Installed	Study	Hydrogeologic Unit	Current Status
GW-7S	PVC	4.00	10.19	8.19	6.2	to	1.2	2	to	7	01/31/94	F	Glacial Till with Sand (1h)	Active
GW-8S	PVC	4.00	7.32	5.32	3.8	to	-1.2	1.5	to	6.5	02/03/94	F	Recent Sand (1d)	Active
GW-9S	PVC	4.00	7.59	5.59	1.6	to	-3.4	4	to	9	02/01/94	F	Recent Sand (1d)	Active
GW-10S	PVC	4.00	10.06	8.06	6.1	to	1.1	2	to	7	01/31/94	F	Fill Material (1a)	Active
GW-10M	PVC	4.00	10.24	8.24	-16.8	to	-21.8	25	to	30	02/04/94	F	Glacial Till with Sand (1h)	Active
GW-11M	PVC	4.00	11.47	9.47	-22.5	to	-27.5	32	to	37	01/18/94	F	Glacial Till / Glaciolacustrine Clay Silt (1f)	Active
GW-12S	PVC	4.00	7.08	5.08	3.6	to	-1.4	1.5	to	6.5	01/27/94	F	Meadow Mat (1b)	Active
GW-12M	PVC	4.00	9.45	7.45	-7.6	to	-12.6	15	to	20	02/08/94	F	Recent Silt and Clay (1c)	Active
GW-13S	PVC	4.00	9.69	7.69	4.7	to	-0.3	3	to	8	02/10/94	F	Glacial Till / Glaciolacustrine Clay Silt (1f)	Active
GW-13D	PVC	4.00	12.52	10.52	-22.5	to	-27.5	33	to	38	05/02/94	F	Glacial Till w/Sand/Glaciolacustrine Clay Silt (1f/1h)	Active
GW-13CS	PVC	4.00	11.97	9.97	-113	to	-118	123	to	128	06/13/94	F	Fine to Med. Sand, Light Gray (5)	Active
GW-14S	PVC	4.00	10.04	8.04	6.5	to	1.5	1.5	to	6.5	01/25/94	F	Shallow Glacial Sand (1e)	Active
GW-15S	PVC	4.00	7.97	5.97	4.5	to	-0.5	1.5	to	6.5	01/26/94	F	Meadow Mat (1b)	Active
GW-16S	PVC	4.00	8.95	6.95	5.5	to	0.5	1.5	to	6.5	01/27/94	F	Recent Silt and Clay (1c)	Active
GW-17S	PVC	4.00	10.38	8.38	6.9	to	1.9	1.5	to	6.5	12/30/93	F	Fill Material / Meadow Mat (1a/1b)	Active
GW-18S	PVC	4.00	9.87	7.87	5.4	to	0.4	2.5	to	7.5	12/10/93	F	Fill Material (1a)	Active
GW-19S	PVC	4.00	10.35	8.35	5.9	to	0.9	2.5	to	7.5	12/09/93	F	Fill Material (1a)	Active
GW-20S	PVC	4.00	17.52	15.52	6.5	to	1.5	9	to	14	02/16/94	F	Glacial Till / Glaciolacustrine Clay Silt (1f)	Active
GW-20M	PVC	4.00	17.48	15.48	-9.5	to	-14.5	25	to	30	02/16/94	F	Glacial Till with Sand (1h)	Active
GW-21S	PVC	4.00	10.19	8.19	4.2	to	-0.8	4	to	9	02/04/94	F	Glacial Till with Sand (1h)	Active
GW-22S	PVC	4.00	11.66	9.66	5.7	to	0.7	4	to	9	02/07/94	F	Glacial Till with Sand (1h)	Active
GW-23S	PVC	4.00	14.10	12.10	10.6	to	5.6	1.5	to	6.5	02/07/94	F	Fill / Recent Silt and Clay (1a/1c)	Active
GW-24S	PVC	4.00	15.17	13.17	8.7	to	3.7	4.5	to	9.5	12/05/93	F	Fill Material (1a)	Active
GW-25S	PVC	4.00	16.08	14.08	9.1	to	4.1	5	to	10	01/14/94	F	Fill Material / Meadow and Mat (1a/1b)	Active
GW-26S	PVC	4.00	11.49	9.49	6.0	to	1.0	3.5	to	8.5	12/08/93	F	Fill Material (1a)	Active
GW-27M	PVC	4.00	15.38	13.38	-2.6	to	-7.6	16	to	21	02/14/94	F	Shallow Glacial Sand (1e)	Active
GW-27D	PVC	4.00	14.78	12.78	-24.2	to	-29.2	37	to	42	02/11/94	F	Reworked:Glacial-Cret. Mix, Sand w/Fines (1i)	Active
GW-28S	PVC	4.00	12.40	12.40	-2.6	to	-7.6	15	to	20	02/25/94	F	Glacial Till / Glaciolacustrine Clay Silt (1f)	Active
GW-28D	PVC	4.00	13.32	13.32	-26.7	to	-31.7	40	to	45	02/24/94	F	Deep Glacial Sand/Reworked Sediment (1h)	Active
LW-1S	PVC	4.00	26.66	19.60	-1.4	to	-6.4	21	to	26	02/01/94	F	Waste / Recent Sand (1a/1d)	Active
LW-2S	PVC	4.00	33.30	31.30	6.3	to	1.3	25	to	30	01/25/94	F	Waste (1a)	Active
LW-3S	PVC	4.00	30.23	28.23	-0.8	to	-5.8	29	to	34	01/06/94	F	Waste / Recent Sand and Clay / Till (1a/1c)	Active
LW-4S	PVC	4.00	41.69	39.69	-1.3	to	-6.3	41	to	46	12/21/93	F	Waste (1a)	Active
LW-5S	PVC	4.00	30.80	28.80	0.8	to	-4.2	28	to	33	12/14/93	F	Waste (1a)	Active
PZ-1BR	PVC	2.00	12.40	10.40	-139.6	to	-144.6	150	to	155	05/19/94	F	Weathered Bedrock - Manhattan Schist (8)	Active
PZ-2BR	PVC	2.00	18.40	16.40	-151.6	to	-156.6	168	to	173	04/05/94	F	Weathered Bedrock - Manhattan Schist (8)	Active
SAC-1	PVC	4.00	27.33	24.83	-36.2	to	-41.2	61	to	66	04/09/97	G	Reworked:Glacial-Cret. Mix, Sand w/Fines (1i)	Active

Fourteen monitoring wells were installed within the glacial sediments and completed using the hollow stem augering method. The auger bit drilled a bore hole approximately 10" in diameter, and split spoon samples were taken continuously until the desired well depth was achieved. Split spoon samples were field screened with an OVM-PID by the on-site geologist. Soils were then classified according to visual observations made in the field. A photograph of each split spoon was taken and a representative sample of the split spoon was placed in a glass sample jar. Archived soil sample are stored on-site. Soil boring logs, notes, and other personal observations are recorded in soil boring logs which can be found in Appendix G.

Following installation, all newly installed monitoring wells were properly developed using a surge block, hand bailers, and a submersible and/or centrifugal pump. Every effort was made to attain water with a turbidity of less than 100 NTUs.

3.4.2.2 Geoprobes

To supplement the existing groundwater monitoring system and to identify potential DNAPL zones, three temporary sampling points were installed. The Geoprobe system used allowed for the collection of discrete interval groundwater samples from the selected sampling locations listed.

- EPA recommended geoprobe (EPA-2s), 20 feet deep
- 1 geoprobe (SAC-13), 15 feet deep
- 1 geoprobe (SAC-14), 30 feet deep.

A complete geologic log for each location appears in Appendix G along with boring log information from monitoring wells. Two groundwater samples were collected at each of the geoprobe locations. See table below for the summary of results for field readings. Field readings taken during geoprobe sampling are summarized below:

Geoprobe Sample Point	Interval (ft)	pH	Cond. (ms/cm)	Turb. (ntu)	DO (mg/l)
EPA-2S	10-12 18-29	7.8 7.92	.860 .804	999 219	0.44 0.41
SAC-13	7-9 13-15	6.77 6.91	1.25 4.49	73 191	9.85 9.08
SAC-14	6-8 28-30	4.39 5.43	.694 .552	40 169	9.03 7.88

Groundwater samples were taken at the water table interface and at the final depth of the geoprobe borehole. Groundwater samples were sent for laboratory analysis for TCL VOC's and the leachate parameters ammonia, COD, TOC and Total Cyanide. EPA-2 was installed to address concern over VOC's detected Southeast of RI well GW-23S, which during this investigation was found to contain floating product that appeared to be a heavy oil. However, no petroleum staining was noted at the EPA-2S geoprobe location.

T. 3-2

Summary of Permeability Testing Data

Brookfield Avenue Landfill Remedial Investigation, Staten Island, New York

Well/Boring I.D.	Depth (feet)	Geologic Unit	Grain Size Permeability (cm/sec)	Laboratory Test Data Permeability (cm/sec)	Slug Test Permeability (cm/sec)	
					Falling Head	Rising Head
LW-4S*	41-46	Waste Material	------	------	6.89E-06	1.24E-05
LW-1S*	21-26	Waste Material	------	------	7.08E-04	2.77E-04
D-1	9-11	Fill	6.62E-03	------	------	------
C-21D	35-37	Recent Sand	7.92E-03	------	------	------
C-39D	28-30	Recent Sand	1.10E-02	------	------	------
C-35D	8-10	Recent Sand	1.13E-02	------	------	------
C-18D	85-87	Recent Sand	1.88E-02	------	------	------
D-4	34-36	Recent Sand	1.88E-02	------	------	------
C-37D	50-52	Recent Sand	2.22E-02	------	------	------
EB-14*	12-14.5	Recent Silt and Clay	------	4.80E-08	------	------
MW-4A	10	Recent Silt and Clay	------	5.90E-08	------	------
WS-10	10-12	Recent Silt and Clay	------	7.50E-08	------	------
C-26D	15-17	Recent Silt and Clay	------	8.10E-08	------	------
WS-20	16-17	Recent Silt and Clay	------	1.90E-07	------	------
GW-12M*	12-14.5	Recent Silt and Clay	------	1.10E-06	------	------
GW-12M*	15-20	Recent Silt and Clay	------	------	9.36E-05	1.01E-04
WS-16	10-12	Recent Silt and Clay	------	1.20E-05	------	------
MW-3	11.7	Recent Silt and Clay	------	2.30E-05	------	------
WS-20	15-16	Recent Silt and Clay	------	6.00E-05	------	------
D-1	39-41	Glacial Sand	1.33E-02	------	------	------
WS-13	15-17	Glacial Sand	1.88E-02	------	------	------
D-15	42-44	Glacial Sand	4.64E-01	------	------	------
GW-20M*	25-30	Glacial Sand	------	------	4.07E-04	1.06E-04
GW-13D*	33-38	Glacial Sand	------	------	1.19E-03	2.11E-03
GW-28D*	40-45	Glacial Sand / Reworked	------	------	7.61E-04	5.64E-04
D-12	36-38	Glacial Till w/Sand	1.32E-02	------	------	------
GW-10M*	25-30	Glacial Till w/Sand	------	------	6.21E-03	1.06E-02
GW-11M*	32-37	Glacial Till w/Sand	------	------	2.21E-04	3.89E-03
EB-13*	40-42.5	Glacial Till	------	6.20E-08	------	------
MW-2	10.8	Glacial Till	------	6.90E-08	------	------
D-5	20-22	Glacial Till	------	8.60E-08	------	------
C-27S	65-67	Glacial Till	4.64E-03	------	------	------
MW-3	22	Glaciolacustrine Clay	------	2.80E-08	------	------
MW-4	24	Glaciolacustrine Clay	------	4.00E-08	------	------

Table 3-3

Monitoring Well Casing Elevation and Water Level Measurements

Brookfield Avenue Landfill Remediation Project

All Measurements are in feet.

Well Number	Hydrogeologic Unit	Top of Casing Elevation (ft MSL)	June 24, 1994			June 20, 1997		
			Time	DTW (ft)	WLE (ft MSL)	Time	DTW (ft)	WLE (ft MSL)
GW-1M	Glacial Till / Glaciolacustrine Clay Silt (1f)	44.71	08:00	30.55	14.16	10:33	29.27	15.44
GW-1CS	Fine to Med. Sand, Light Gray (5)	44.38	07:30	39.20	5.18	10:35	37.51 *	6.87
GW-2S	Glacial Till with Sand (1h)	43.77	09:35	36.50	7.27	11:20	36.08	7.69
GW-3S	Glacial Till / Glaciolacustrine Clay Silt (1f)	13.96	10:02	6.56	7.40	10:15	6.12	7.84
GW-4S	Meadow Mat (1b)	19.00	12:02	11.51	7.49	10:02	10.34	8.66
GW-5S	Glacial Till / Glaciolacustrine Clay Silt (1f)	12.32		No Data		10:28	6.76	5.56
GW-6S	Glacial Till / Glaciolacustrine Clay Silt (1f)	10.27	10:20	7.67	2.60	09:05	2.55	7.72
GW-7S	Glacial Till / Glaciolacustrine Clay Silt (1f)	10.19	10:25	4.82	5.37	09:15	4.20	5.99
GW-8S	Recent Sands (1d)	7.32	09:36	1.92	5.40	08:33	2.09	5.23
GW-9S	Recent Sands (1d)	7.59	09:42	1.80	5.79	09:59	2.85	4.74
GW-10S	Recent Sands (1d)	10.06	12:02	1.44	8.62	08:24	1.24	8.82
GW-10M	Glacial Till with Sand (1h)	10.24	12:04	6.26	3.98	08:25	5.94	4.30
GW-11M	Glacial Till with Sand (1h)	11.47	11:57	4.50	6.97	09:32	4.41	7.06
GW-12S	Meadow Mat (1b)	7.08	11:36	2.14	4.94	09:05	2.11	4.97
GW-12M	Recent Silt and Clay (1c)	9.45	10:39	4.58	4.87	09:07	4.33	5.12
GW-13S	Glacial Till / Glaciolacustrine Clay Silt (1f)	9.69	10:18	3.77	5.92	09:02	3.57	6.12
GW-13D	Glacial Till with Sand (1h)	12.52	10:20	6.06	6.46	09:00	5.88	6.64
GW-13CS	Very Fine Sand, Light Gray (4a)	11.97	10:20	5.26	6.71	08:57	5.37 *	6.60
GW-14S	Shallow Glacial Sand (1e)	10.04	10:11	3.94	6.10	08:53	4.03	6.01
GW-15S	Meadow Mat (1b)	7.97	10:06	2.07	5.90	08:45	3.02	4.95
GW-16S	Recent Silt and Clay (1c)	8.95	10:53	3.14	5.81	08:50	4.30	4.65
GW-17S	Fill Material(1a) / Meadow Mat(1b)	10.38	10:59	4.34	6.04	08:55	4.21	6.17
GW-18S	Fill Material (1a)	9.87	09:52	4.14	5.73	09:00	4.02	5.85
GW-19S	Fill Material (1a)	10.35	09:48	3.60	6.75	09:15	3.38	6.97
GW-20S	Glacial Till with Sand (1h)	17.52	12:20	10.29	7.23		No Data	
GW-20M	Deep Glacial Sand (1g)	17.48	12:15	12.47	5.01	10:35	11.04	6.44
GW-21S	Shallow Glacial Sand (1e)	10.19	09:40	4.94	5.25	09:30	4.83	5.36
GW-22S	Glacial Till / Glaciolacustrine Clay Silt (1f)	11.66	09:45	4.95	6.71	09:35	4.05	7.61
GW-23S	Fill Material(1a)/ Recent Silt and Clay(1c)	14.10	09:50	4.94	9.16	09:45	4.25	9.85
GW-24S	Fill Material (1a)	15.17	11:23	8.25	6.92	09:44	7.40	7.77

Table 3-3

Monitoring Well Casing Elevation and Water Level Measurements

Brookfield Avenue Landfill Remediation Project

All Measurements are in feet.

Well Number	Hydrogeologic Unit	Top of Casing Elevation (ft MSL)	June 24, 1994			June 20, 1997		
			Time	DTW (ft)	WLE (ft MSL)	Time	DTW (ft)	WLE (ft MSL)
SAC-4	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	16.04	-	-	-	10:02	8.06	7.98
SAC-5	Silty Clay w/ Fine Sand (2a)	18.47	-	-	-	10:06	12.14	6.33
SAC-6	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	14.19	-	-	-	09:30	9.52	4.67
SAC-7	Very Fine Sand, Light Gray (4a)	43.86	-	-	-	10:47	23.74 *	20.12
SAC-8	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	13.93	-	-	-	10:12	8.37	5.56
SAC-9	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	12.51	-	-	-	09:20	6.76	5.75
SAC-10	Very Fine Sand, Light Gray (4a)	13.72	-	-	-	09:17	6.10 *	7.62
SAC-16	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	38.21	-	-	-	10:38	20.98	17.23
SAC-17	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	37.99	-	-	-	10:39	20.85	17.14
SAC-18	Glacial Till with Sand (1h)	24.76	-	-	-	10:20	13.51	11.25
SAC-19	Silt and Clay, Light Gray (4), w/Fine Sand	28.85	-	-	-	10:26	16.75 *	12.10
SAC-20	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	30.89	-	-	-	12:15	17.81	13.08
SAC-21	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	14.88	-	-	-	09:42	9.50	5.38
EPA-1S	Shallow Glacial Sand (1e)	21.25	-	-	-	10:33	11.32	9.93
EPA-1M	Deep Glacial Sand (1g)	21.43	-	-	-	10:34	7.14	14.29
EPA-2M	Reworked: Glacial - Cret. Mix, Sand w/ Fines(1i)	10.17	-	-	-	12:18	0.23	9.94
GW-29	Very Fine Sand, Light Gray (4a)	15.43	-	-	-	11:40	7.63 *	7.80
GW-30	Fine to Med. Sand, Light Gray (5)	43.93	-	-	-	10:42	36.83 *	7.10
Richmond Crk.	Surface Water	3.11	-	-	-	08:24	1.07	4.18
West Creek	Surface Water	3.23	-	-	-	08:35	1.46	4.69
Central Pond	Surface Water	8.32	-	-	-	09:27	0.77	9.09
East Pond	Surface Water	4.77	-	-	-	08:45	0.23	5.00
East Channel	Surface Water	2.96	-	-	-	09:30	0.88	3.84
West Channel	Surface Water	8.84	-	-	-	09:01	1.30	10.14

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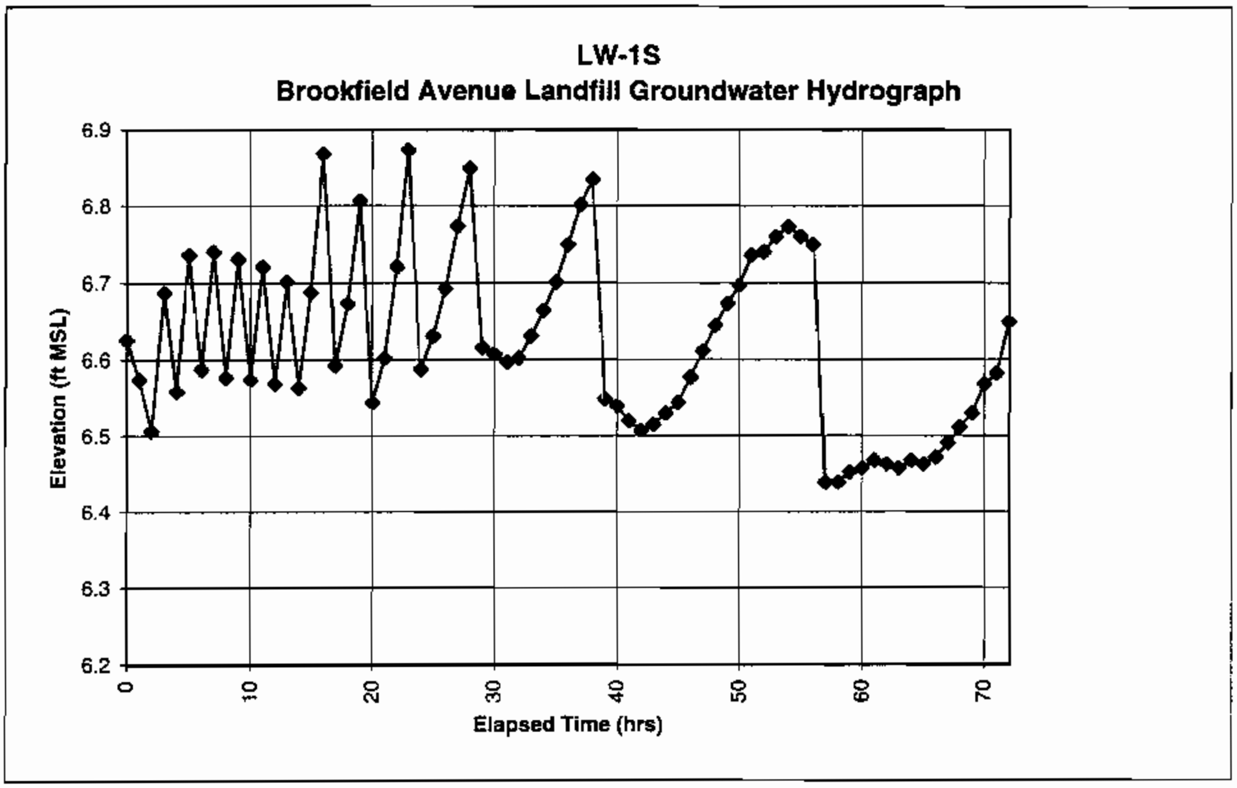
3/23/98

Datum: NGVD, 1929

#:Elevation of 0.0 ft. mark of surface water staff gauges

*: Gauged on 8/18/97.

Figure 3-1
Continuous Hydrograph Data
Brookfield Avenue Landfill Remediation Project



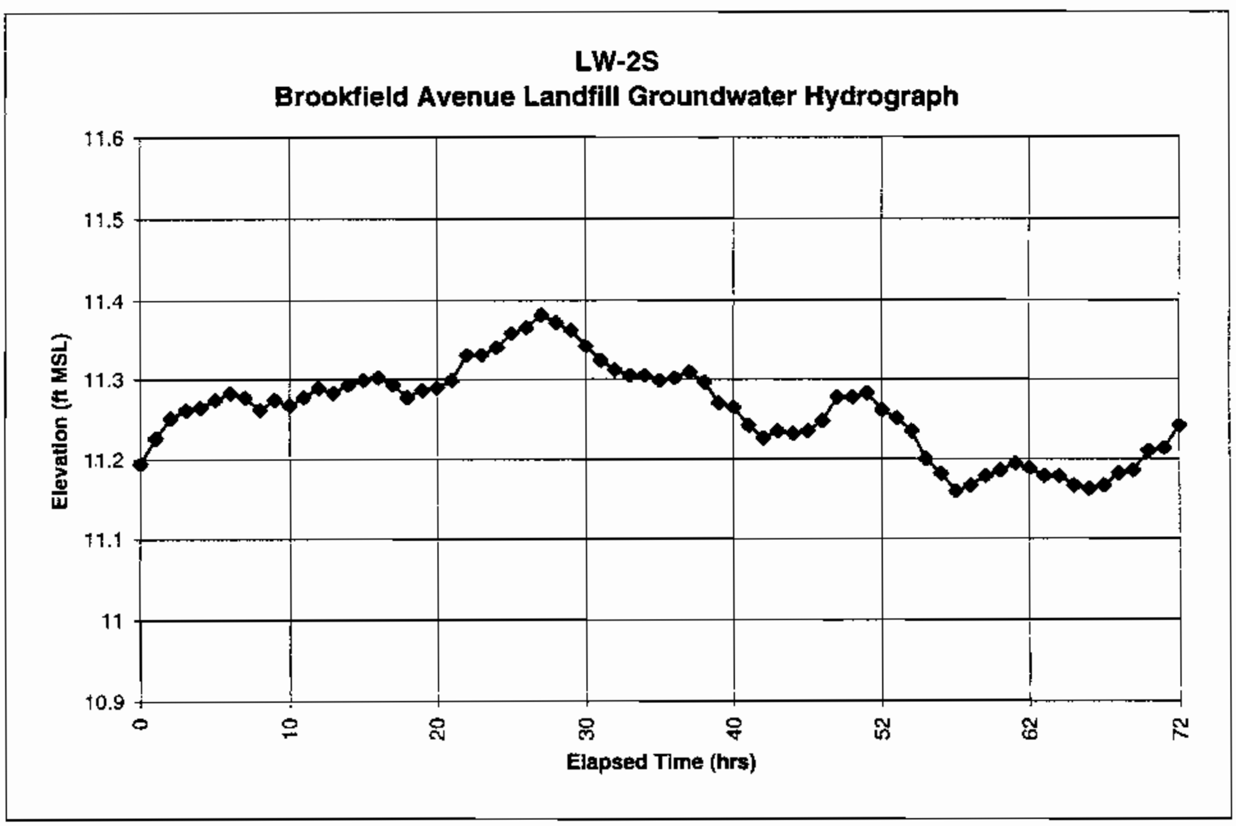
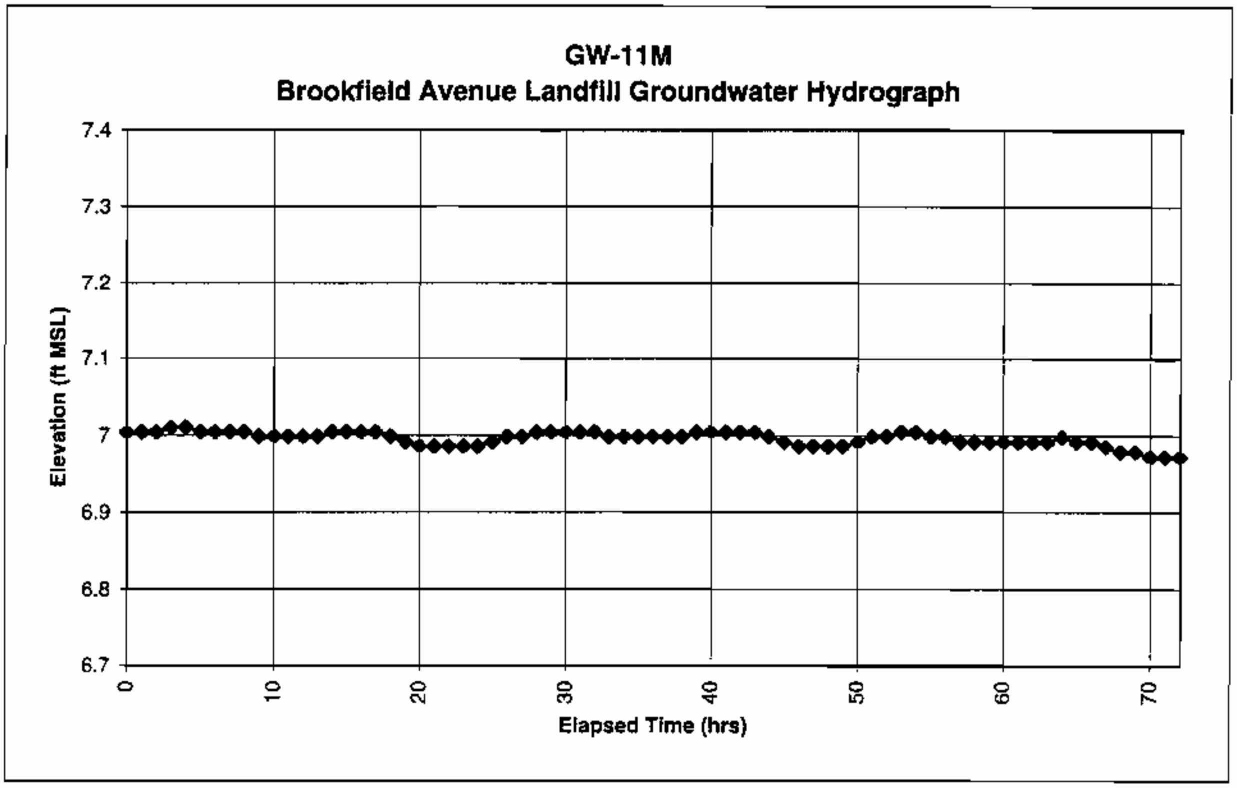
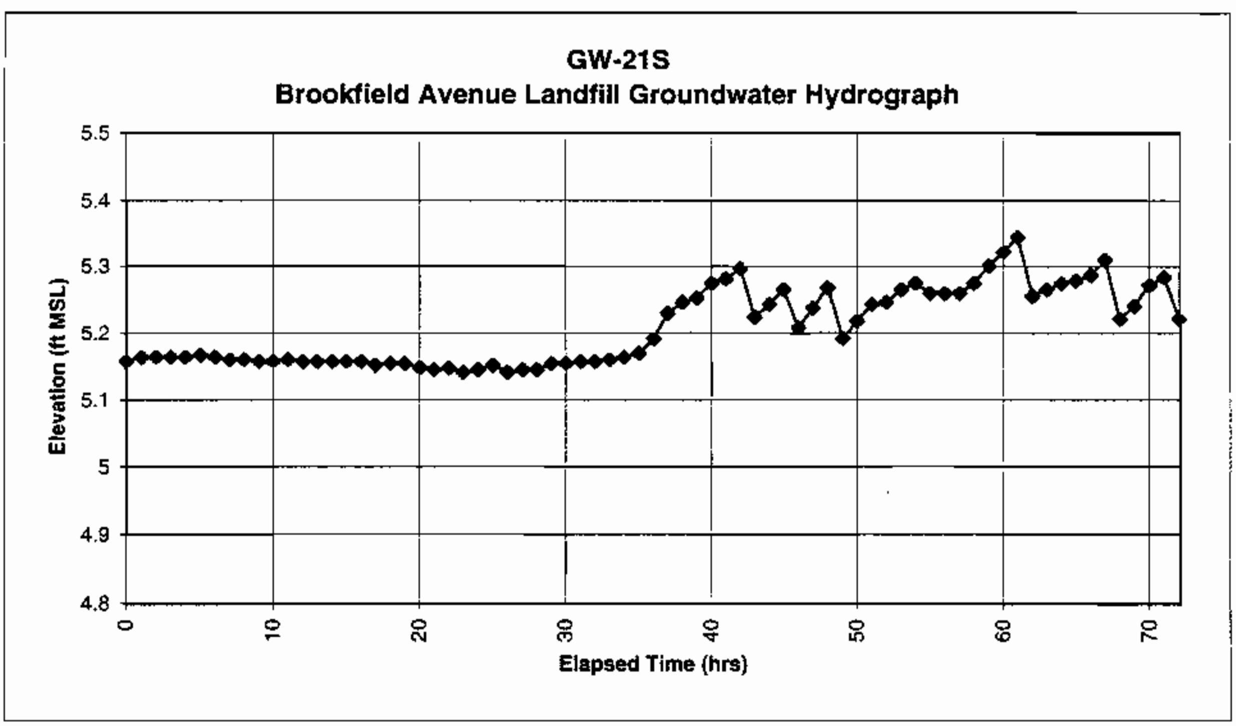


Figure 3-1
Continuous Hydrograph Data
Brookfield Avenue Landfill Remediation Project





On April 1, 1996, a pressure transducer and data logger were set up in Richmond Creek, just north of the west cell of Brookfield Avenue Landfill, to measure water level fluctuations. Pressure transducers were placed in wells PZ-1BR, GW-13CS, D-12, and D-13 to determine the influence of barometric and tidal forces on groundwater levels in these wells. Continuous barometric pressure and water level readings were taken by the data logger at hourly intervals. Readings were recorded for 93 continuous hours.

The data loggers began recording synoptically at 1030 hours, April 1, 1996. The test ended on April 5, 1996, between the hours of 0800 and 0830 hours for all the wells. On April 2, 1996, 0.83" of precipitation was measured in the rain gauge located next to Richmond Creek. For the remainder of the test, no additional precipitation was recorded.

The test took place during a full moon and is representative of near maximum tidal range fluctuations that can be expected during the year. Richmond Creek's maximum tidal range was 4.5 feet from high to low tide during this period.

Graphical plots of data obtained during the four day study are shown in Figure 3-2. For each well, water level fluctuations are plotted against barometric pressure changes and tidal fluctuations as measured in Richmond Creek. Wells GW-13CS, PZ-1BR, and D-12 show minor water level fluctuations due to tidal forces. The graphical plot of well D-13's data does not reveal a clear relationship between water level fluctuations in this well and tidal forces. The maximum water level fluctuation observed during the four day test was 0.28 feet, recorded in well GW-13CS. This well is located closest to Richmond Creek.

CDM's geologic analysis of the site area indicates that the upper cretaceous clay unit (Unit 3) appears to have been eroded away in the western portion of Richmond Creek north of the landfill. This erosion feature was filled with till, glacial sand, and glaciolacustrine clay. This feature is the likely cause of the moderately strong tidal response in well GW-13CS located near Richmond Creek.

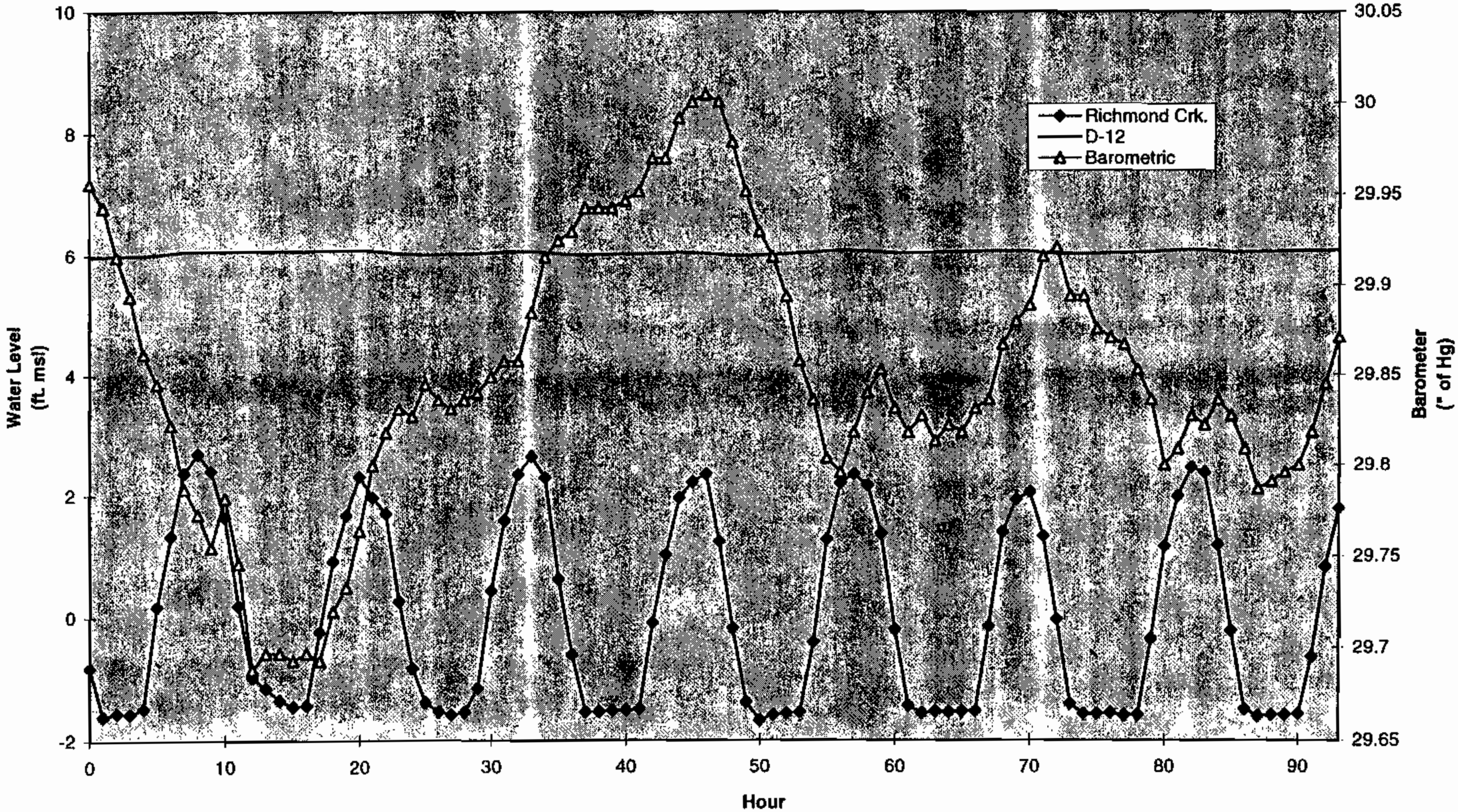
Wells D-12 and D-13 are located approximately 1400 feet south of the cretaceous erosional feature. D-12 is apparently screened in the lower cretaceous sand, while D-13 appears to be screened in a discontinuous and relatively minor sand unit that appears to be located in the confining unit itself. CDM believes that this is the explanation for no significant tidal response in D-13. It is probably screened in the confining unit itself and has a very poor hydraulic connection to tidal fluctuations.

The apparent slight decline in head in D-13 is probably the result of its poor hydraulic connection with significant aquifers. It is probable that the apparent recharge being observed in the other wells will lag considerably in well D-13 because of its apparent location within the confining unit.

For the four day study, the hydraulic head of Richmond Creek remained less than the observed hydraulic heads in the four wells monitored. This data indicates that barometric and tidal fluctuations do not have a significant effect on vertical flow between the Cretaceous aquifer and Upper Glacial aquifer. No vertical hydraulic gradient changes or reversals in flow were observed during testing.

Figure 3-2

Barometric and Tidal Influences on the Cretaceous Aquifer
Brookfield Avenue Landfill: Well D-12
April 1, 1996 - April 5, 1996



CDM Camp Dresser & McKee

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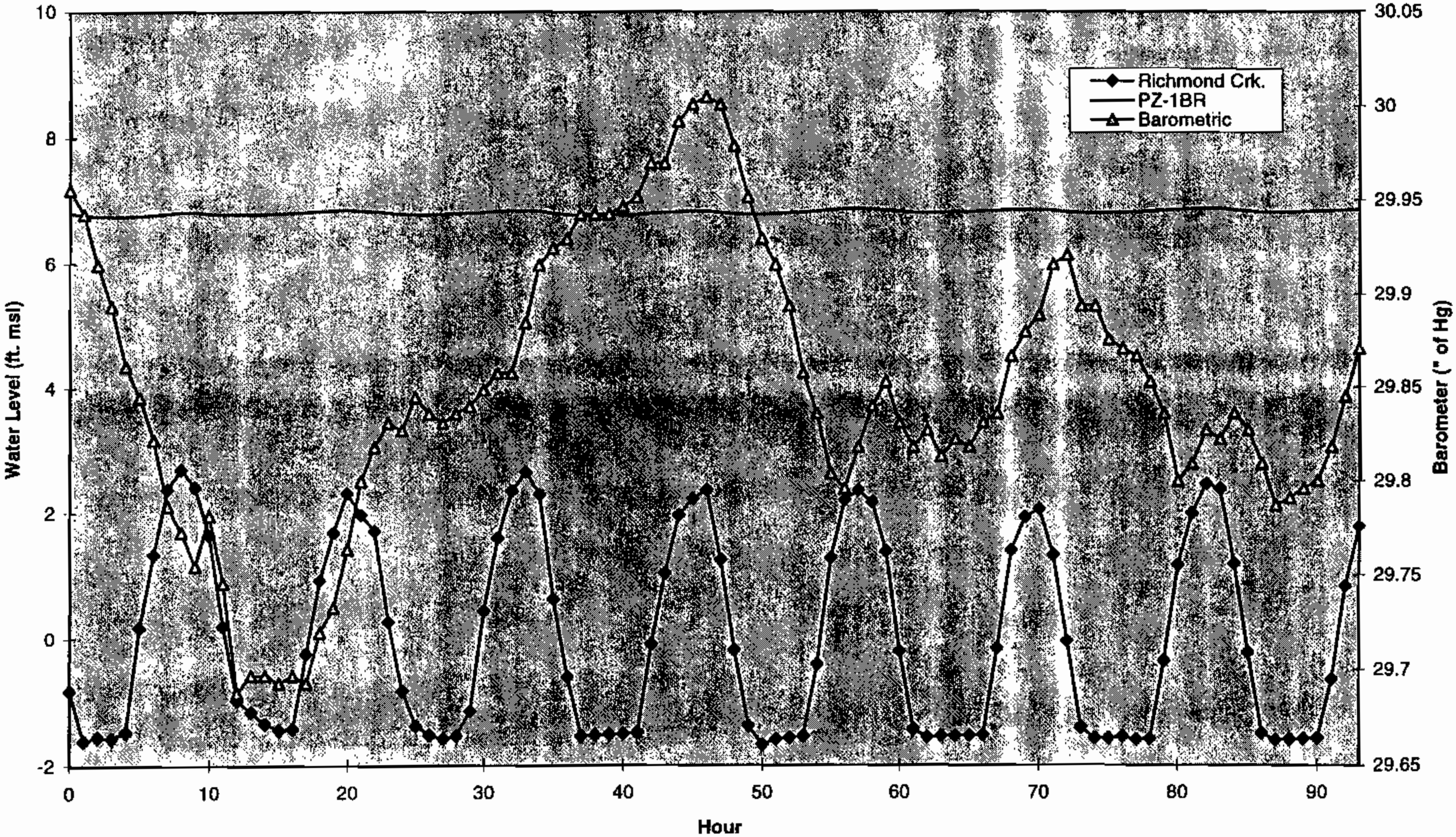
Figure 3-2

Barometric and Tidal Influences on the Cretaceous Aquifer
Brookfield Avenue Landfill: Well PZ-1BR
April 1, 1996 - April 5, 1996



CDM Camp Dresser & McKee

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This data indicates that barometric and tidal fluctuations do not have a significant impact on horizontal flow direction in the Cretaceous aquifer or on vertical flow between the Cretaceous aquifer and the Upper Glacial aquifer.

The time lag between tidal highs and lows and corresponding water level changes observed in the monitoring wells is on the order of two to five hours. The well hydrographs show no clear indication of any nearby unidentified groundwater pumpage in this aquifer.

3.4.2.5 Groundwater Modeling

A mathematical model of groundwater flow was developed to analyze the local groundwater flow regime. The objectives of the groundwater modeling were to:

- assist in gaining greater insight into the groundwater flow patterns at the site,
- assist in determining the direction and movement of groundwater contaminated by leachate, and
- assist in selecting monitoring well locations.

A considerable amount of existing information was available to develop a conceptual model describing the Brookfield Avenue Landfill groundwater flow system. A conceptual model outlines the hydrogeologic features of an area and how these features impact groundwater flow, and provides a qualitative description of an area's groundwater flow field. This conceptual model was first presented in the project workplan (see Figure 3-1, CDM, August, 1993) and further refined during a project workshops on site hydrogeology. The conceptual model, which forms the basis for the numerical computer model, represents a preliminary understanding of the physical system, incorporating geohydrologic boundary conditions, area stratigraphy, direction of groundwater flow and precipitation and recharge quantities.

Primary sources of information included previous Brookfield remedial studies, USGS publications, New Jersey Geological Survey publications, and the NYCDOS Fresh Kills Landfill Interim Hydrogeologic Report (IT Corp, 1992).

The site groundwater flow model was developed using DYNFLOW, a computer model developed by Camp Dresser & McKee Inc. (CDM) that simulates three-dimensional groundwater flow using a finite element technique for solution of the governing equations. DYNFLOW solves both confined and unconfined groundwater flow equations to simulate the behavior of groundwater flow systems under several types of natural and artificial stresses. These stresses include natural and artificial recharge and discharge (e.g. precipitation infiltration, infiltration from or discharge to streams, well withdrawals or injection), and differing boundary conditions.

DYNFLOW has been verified by the International Ground Water Modeling Center, located at the Colorado School of Mines, in Golden, CO. The verification entailed verification of the computer code and modeling theory, testing of the versatility of DYNFLOW's applications and scrutinizing the model documentation. DYNFLOW was determined to be a logical and efficient computer code

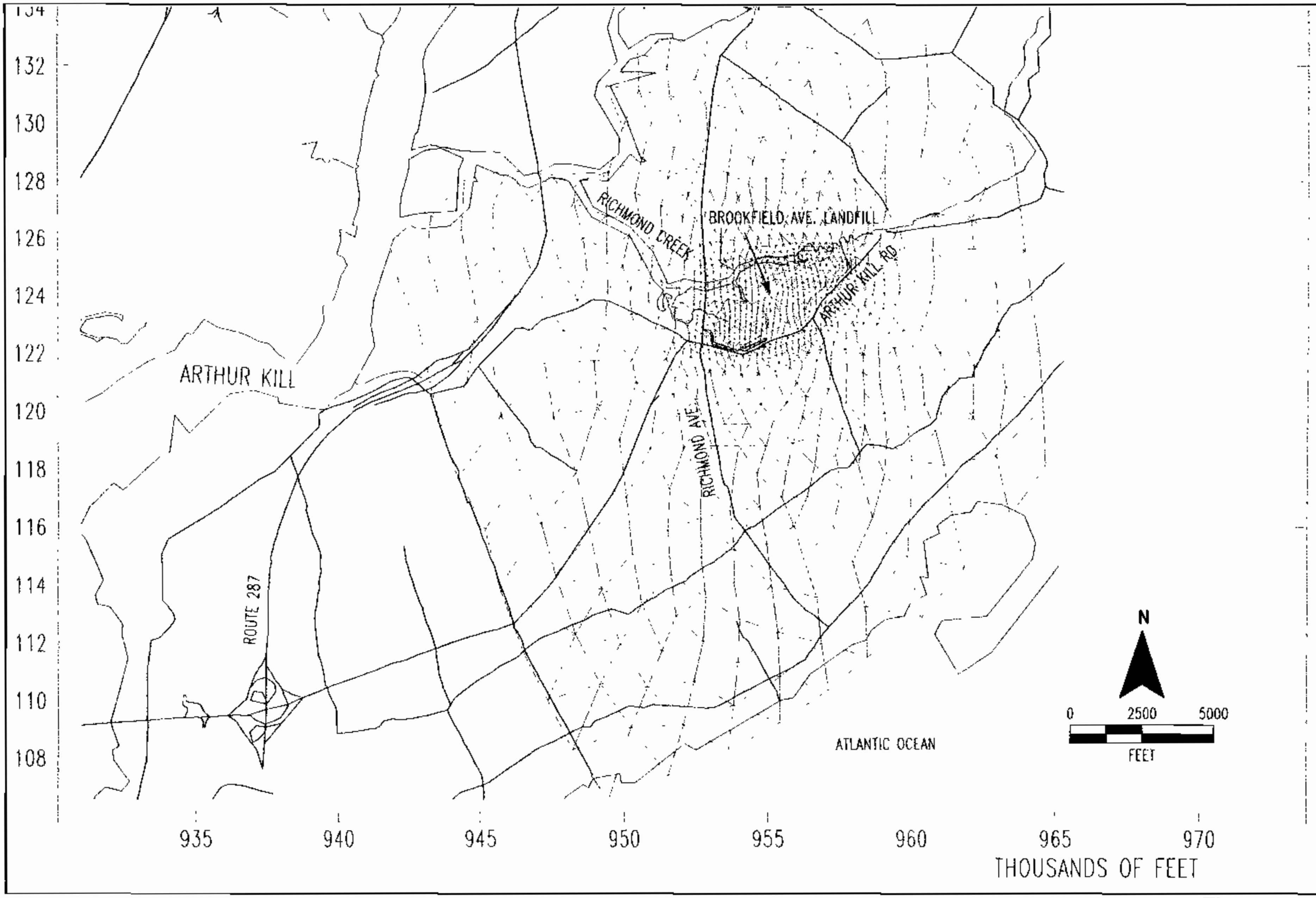

Figure 3-3
Model Finite Element Grid
Brookfield Groundwater Flow Model
Brookfield Avenue Landfill Remediation Project

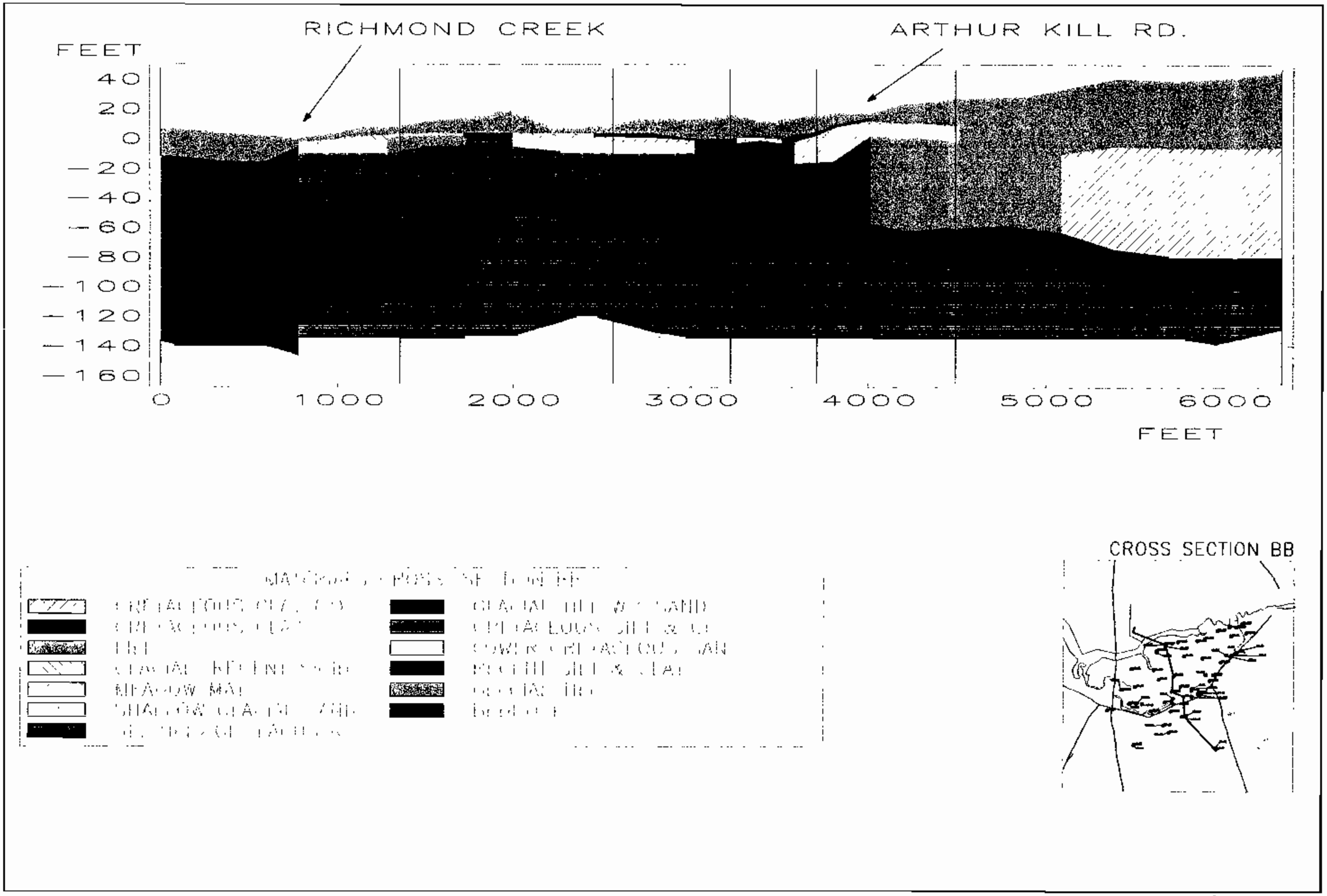

Figure 3-5
Cross Section Through Landfill Showing Stratigraphy
Brookfield Groundwater Flow Model
Brookfield Avenue Landfill Remediation Project

Table 3-4
Summary of Permeability Testing Data
Brookfield Avenue Landfill, Staten Island, New York

Geologic Unit (Code)	Regional Data[1]			Brookfield Site Specific Data				
	Type of Test	Number of Tests	Geometric Mean (ft/day)	Grain Size Permeability (ft/day)	Laboratory Test Data Permeability (ft/day)	Slug Test Permeability (ft/day)	Model Incorporated Conductivity Horizontal (ft/day)	Model Incorporated Conductivity Vertical (ft/day)
Waste Material (1a)	in-situ	86	6.8	18.8	-	0.020 - 2.0	7.0	0.875
Recent Sand (1d)	grain size	37	3.7	22.5 - 63.0	-	-	10.0	0.1
	in-situ	17	0.39					
Recent Silt and Clay (1c)	lab K_v	17	0.00041	-	0.0001 - 0.170	0.27	0.2	0.02
	lab K_h	14	0.00015					
Glacial Sand (1e, 1g)	grain size	27	5.4	37.8 - 53.35	-	0.30 - 6.0	10.0	1.0
	in-situ	9	1.8					
Meadow Mat (1b)	-	-	-	-	-	-	0.2	0.02
Glacial Till w/Sand (1h)	-	-	-	37.5		0.63 - 30.0	6.0	1.0
Glacial Till (1f)	grain size	47	0.045	13.2	0.00018 - 0.00024	-	0.5	0.1
	lab K_v	7	0.00028					
	in-situ	14	0.036					
Glaciolacustrine Clay (1f)	lab K_v	73	0.00047	-	0.0001 - 0.00007	-	0.1	0.01
	lab K_h	91	0.00049					
Cretaceous Clay (3)	lab K_v	27	0.00022	-	0.0001	-	0.01	0.002
	lab K_h	23	0.00016					
Cretaceous Silt & Clay (4)	-	-	-	-	-	-	10.0	0.1
Cretaceous Sand (7)	grain size	91	0.63	9.3 - 44.3	0.03 - 1.19	23.1	20.0	0.2
	in-situ	20	4.2					
Weathered Bedrock (8, 9)	in-situ	17	0.057	-	-	0.0211 - 0.048	0.05	0.05

[1] As compiled in Fresh Kills Landfill Study, IT Corp, 199_

The model was tested by comparing computed results with available field data from synoptic water level readings taken in June 1994 and June 1997. Regional flow patterns predicted by the model were checked against a composite water table map of Staten Island (1931-1986) prepared by Soren (1988). Measured water levels in the area's observation and pumping wells represent the groundwater system's response to varying hydrologic and hydraulic conditions- -the model's ability to reproduce the observed water levels is a good indication of its ability to represent the physical system. Stream baseflow reflects the water table aquifer's response to varying changes in the hydrologic system (i.e. pumping, changes in precipitation, etc.), since under natural conditions groundwater provides 85 percent of streamflow. The model's ability to represent the baseflow of the streams is therefore another measure of its reliability.

During the initial stages of the calibration process, preliminary estimates of hydrogeologic properties and boundary conditions were tested to increase the understanding of the system and investigate the validity of the conceptual model, including horizontal and vertical extent of the finite element grid, the number and characterization of model layers used to represent the island's stratigraphy, and the boundary condition assumptions. The relative importance of the different parameters on the solution was also evaluated during the early model simulations, to help focus subsequent calibration efforts.

Results of initial calibration simulations were compared to the general magnitude and configuration of the published USGS contours of the water table within the Glacial/Recent aquifer and the piezometric surfaces within the Cretaceous aquifer. The basic conceptual model assumptions were verified, as the initial calibration simulations were successful in providing reasonable estimates of the documented regional groundwater flow patterns. It is important to note at this point that numerous onsite monitoring wells have extensively characterized the Glacial/Recent aquifer. The number of onsite wells screened in the Cretaceous aquifer is significantly less, hence these areas are not as well characterized. The Cretaceous aquifer is monitored less because the conceptual model indicates that it does not play a significant role in contaminant migration.

The model was then "fine-tuned" by refining assumptions and reviewing and adjusting the input parameters (hydraulic conductivity, recharge, boundary conditions, stratigraphic elevations) within the pre-specified expected ranges, until the computed groundwater elevations and flows matched the observed target values within acceptable limits. This iterative procedure was extensive for the model, due to the complexity of the groundwater system.

Pumping and recharge values can typically be assigned with confidence for localized site-specific modeling projects where input parameters such as pumping well locations and rates are well defined. Hydrogeologic layering and property assignments can also be defined more easily on a local scale when site-specific data are available. The most uncertainty is generally associated with hydraulic conductivities which are, therefore, a main calibration parameter for local site models.

For the calibration targets, the model reasonably depicts the observed heads. A comparison of the observed water levels of June, 1997, with the model simulated water levels is shown in Figure 3-6. A comparison of the calculated and observed vertical hydraulic gradients is shown in Table 3-5. The model predictions of flow in the Upper Glacial aquifer are very good in the Brookfield area as they

Table 3-5

Calculated vs. Observed Vertical Gradients

Brookfield Avenue Landfill - Remedial Investigation

Well Cluster	*Unit*	*Screen Midpoint (ft. MSL)*	*Vertical Distance*	*6/20/97 Head (ft. MSL)*	*Actual Vertical Gradient*	*Model Calculated Head*	*Model Calculated Vertical Gradient*
PZ-1BR	8	-142.1	144.3	6.81	**0.00478**	6.54	**0.00972**
GW-13S	1f	2.2		6.12		5.14	
GW-13CS	4a	-115.5	117.7	6.60	**0.00408**	6.51	**0.01165**
GW-13S	1f	2.2		6.12		5.14	
PZ-1BR	8	-142.1	117.1	6.81	**0.00145**	6.54	**-0.00026**
GW-13D	1h	-25		6.64		6.57	
GW-13CS	4a	-115.5	90.5	6.60	**-0.00044**	6.51	**-0.00070**
GW-13D	1h	-25		6.64		6.57	
PZ-2BR	8	-154.1	158.6	6.78	**-0.01185**	9.71	**-0.00297**
GW-4S	1b	4.5		8.66		10.18	
PZ-2BR	8	-154.1	142.6	6.78	**0.00316**	9.71	**-0.00356**
SAC-5	2a	-11.5		6.33		10.21	
GW-28D	1g	-29.2	24.1	5.99	**0.01618**	7.96	**0.09349**
GW-28S	1f	-5.1		5.60		5.71	
GW-1CS	5	-106.1	85.3	6.87	**-0.10047**	9.41	**-0.02093**
GW-1M	1f	-20.8		15.44		11.19	
D-13	4a	-101.4	96.4	7.15	**-0.02644**	9.32	**-0.00467**
D-14		-30.9		9.70		9.77	
D-12	5	-139.9	134.9	6.92	**-0.02060**	9.21	**-0.00413**
D-14		-30.9		9.70		9.77	

The hydrologic continuity equation for any system is:

$$I - Q = \frac{ds}{dt}$$

where
I = inflow in volume/time
Q = outflow in volume/time
ds/dt = change in storage in volume/time

For this analysis, long term average conditions are sought, so it is assumed that no change in storage occurs (ds/dt = 0). As a result, inflow must equal outflow to achieve mass balance.

Inflows to the system include:

Leachate generation (caused by recharging precipitation through solid waste)
Horizontal Glacial/Recent aquifer groundwater flow
Upward leakage from the Cretaceous aquifer

Outflows from the system:

Seepage to Richmond Creek
Seepage to perimeter drainage channels and ponds
Downward leakage to the Cretaceous aquifer

A schematic of the system with estimated flows is shown in Figure 3-8.

The leachate generation term (as developed by the HELP model) represents the result of numerous hydrologic processes such as precipitation, evapotranspiration, runoff, and changes in soil moisture.

Quantitative estimates of groundwater and leachate flows were made by coupling the groundwater flow model generated 3-dimensional flowfield with Darcy's Law.

$$Q = -K A \, dh/dl$$

where

Q = flow $[L^3/t]$
K = hydraulic conductivity [L/t]
A = area $[L^2]$
dh/dl = hydraulic gradient [0]

Table 3-6 provides a summary of the vertical and lateral flow estimates of the site.

The net amount of water flowing vertically down through the Cretaceous clay confining unit at the site was determined to be approximately 2.5 million gallons per year (mgal/yr). CDM estimated

Table 3-6
Water Balance

Inflow:	mgal/yr	
Recharge to Landfill (Waste containing areas only)	34.9	
Lateral Flow In:		
From Residential Area (Within Shallow Flow System)	1.2	
Total Inflow =	35.6	
Outflow:		
Vertical Flow Between Aquifers:		Percent of Leachate
Net Seepage to Cretaceous Aquifer from Shallow Flow System	2.5*	3.5%*
Lateral Flow Out:		
To Residential Area (Within Shallow Flow System)	< 0.1	< 0.3%
Discharge to :		
Richmond Creek	20.3	58.1%
West Arthur Kill Rd. Drainage Channel	5.1	14.7%
West Creek	1.6	4.7%
East Arthur Kill Rd. Drainage Channel and Pond	5.1	14.7%
Central Pond	1.4	4.0%
Total Outflow =	36.1	

* Although 2.5 mgal/yr is predicted to flow to the Cretaceous aquifer, approximately 1.2 mgal/yr of this flow is estimated to be "clean" groundwater originating from offsite, and 1.3 mgal/yr of this flow is leachate. Therefore, only 3.5% of the leachate produced is estimated to flow into the Cretaceous aquifer.

(w:brookn/water)

that about 1.2 mgal/yr of this flow comes from Glacial/Recent aquifer groundwater flowing into the site from under Arthur Kill Road. As a result, it is estimated that approximately 1.3 mgal/yr or 3.5% of Brookfield Avenue landfill leachate reaches the Upper Cretaceous aquifer. However, the actual contribution of flow from Glacial/Recent Aquifer to the Cretaceous aquifer is difficult to predict due to the complicated flow patterns of the shallow flow system. Therefore, a conservative estimate of leachate reaching the Cretaceous aquifer would be less than ten percent. Modeled groundwater travel times indicate that it takes more than 30 years for leachate to reach the Cretaceous aquifer. The simulated areas of seepage *down to* and *up from* the Cretaceous aquifer are shown in Figure 3-9.

The amount of leachate flowing laterally from the site in the shallow flow system was estimated individually for the following areas: Richmond Creek, the Arthur Kill Rd. drainage channels (east and west) and the east creek (canal) entering the west side of the site and terminating at the edge of the west cell. Additionally, the flow to the central pond at the western end of the east cell was estimated. Less that 0.1 mgal/yr of leachate within the shallow flow system was estimated to temporarily leave the site along the south boundary and enter the residential area. Because more groundwater is estimated to flow into the site from the south than leave, a net flow *into* the landfill from the residential area in the Glacial/Recent aquifer is predicted.

Leachate Migration. As shown in Figure 3-7, regional groundwater flow south of the site dominates the minor flow from the landfill because it is of much greater head. The radial flow from the landfill which starts in a southerly direction is intercepted by drainage channels, which discharge to Richmond Creek. It is possible that a small quantity of leachate may migrate beneath Arthur Kill Road in the Miles/Giffords Ave. area and again in the Brookfield/Abingdon Ave. area. It is estimated that migration would not travel more than 100 feet south of Arthur Kill Rd. before flowing back to the site and discharging in drainage channels.

Model results indicate that the drainage channels, because they are located in a regional groundwater discharge area are very effective barriers to leachate migration. However, a small amount may flow south across Arthur Kill Rd. where the perimeter drainage channels are not present, as discussed above. However, the net flow within the shallow flow system remains *into* the landfill from the residential area, therefore, it is estimated that pollutants would not travel far, south of Arthur Kill Rd before returning in a northward flow direction.

Leachate Generation. Assuming that all rainfall that infiltrates the landfill is contaminated by the buried waste, approximately 35 million gallons per year of leachate is generated. This is approximately 67 gpm. About 92 percent or 32.1 million gallons per year (61 gpm) discharges into Richmond Creek or drainage channels that ultimately discharge into Richmond Creek. Diurnal tidal flow into and out of Fresh Kills is tens of thousands of gallons per minute (Wehran, 1984). In addition, freshwater streamflow near St. Andrews Church adds more than 450 gpm to Richmond Creek. The tidal flow, and to a lesser extent the streamflow, greatly dilutes leachate flowing into the creek.

Model estimates indicate that approximately 3.5 percent or 1.27 million gallons per year (2 gpm) of leachate leaks into the underlying Cretaceous aquifer. It takes in excess of 30 years for the leachate to reach this aquifer. This leakage may occur first in an area onsite near the Eltingville pump station because of the site hydrogeology. A particle track analysis was performed at hot spot locations within the east and west cells to further examine the contribution of leachate to the total net flow to the Cretaceous aquifer. Using this approach, particles were found to migrate to the Cretaceous aquifer in very limited areas. See Figures 5-2 and 5-3 in Section 5.3.1 for the predicted location in year 2025 based on a source release beginning in 1966 and assuming annual average conditions and no remedial measures for the entire duration.

Capping the landfill in accordance with NYCRR Part 360 regulations will greatly reduce this potential leakage.

Historical Streambed Influence. The historic streambed that is oriented along Abingdon Avenue was simulated in the groundwater flow model. Model results indicate that the streambed does not cause leachate to flow into the residential area. In fact, it appears to cause more groundwater to flow into the Brookfield site.

Private Well Pumping Influence. The three private wells within 3,500 ft. of the site were simulated to pump continuously at their estimated maximum capacity. Model results indicate that pumping these specific wells does not draw leachate offsite.

Confining Unit Influences. The "composite" and Cretaceous clay confining units are very effective in preventing groundwater contamination from migrating into the deeper Cretaceous aquifer. It is estimated that only about 3.5 percent of leachate can migrate into the deeper aquifers and that it takes in excess of thirty years to travel there. The effectiveness of the confining units could be improved if the landfill was capped and if the hydraulic stress on the Cretaceous aquifer was reduced (the stress is apparently caused by groundwater pumping in southern Staten Island or Northern New Jersey).

The possible absence of the Upper Cretaceous Clay confining unit at the northwest portion of the site may not be a factor in allowing leachate to flow into the lower aquifer. The presence of the Glaciolacustrine Clay in this area and the proximity to Richmond Creek, an area of high discharge, produces strong lateral flows towards the creek. Additionally, the model predicts an upward gradient which is also seen in the actual field data from the GW-13/PZ-1BR cluster.

3.4.2.6 Geophysical Logging

Geophysical logging of four deep monitoring wells was performed during CDM's Remedial Investigation Phase II (1997). A gamma probe was lowered down the entire length of each monitoring well to produce a natural gamma activity log found in Appendix N. The following wells were logged using the natural gamma logging technique:

- SAC-10 Depth= 122 ft.
- SAC-19 Depth= 122.8 ft.
- GW-29 Depth= 126 ft.
- GW-30 Depth= 176 ft.

feature composed of glacial till material which marks the southernmost advancement of a continental glacier which flowed north to south across Staten Island.

At the Brookfield Avenue Landfill erosion and deposition of sediments by glacial processes has played an important role in forming the hydrogeologic setting of this area. As glacial ice moved south from the consolidated bedrock region near LaTourette Park across the fall line to the more easily eroded Raritan formations the base of the glacier scoured away the upper portions of the Raritan formation in the northern portion of the site. South of the landfill we see a sequence of moderate red brown silt, sand, and gravel composing the terminal moraine material which unconformably overlies the thickest section of Raritan formations which were left unaffected by the glacial scouring in the southern portion of the site. When the glacier receded meltwaters formed glacial lakes dammed up by the topographically high terminal moraine. As a result we tend to see thicker sequences of glaciolacustrine clay (or glacial lake) deposits in the northern portion of the site where the upper Raritan formations are absent. In the southern area of the site, glacial sands are encountered with greater frequency. These are believed to be the remains of glacial eskers (glacial streams) which deposited coarser material at the foot of the terminal moraine. These glacial lakes have slowly filled with sand and silt from fluvial processes forming wetlands in Staten Island. Brookfield Avenue Landfill was constructed upon a wetland formed by this type of process. This setting is conceptualized in Figure 3-10.

Information gathered during the hydrogeologic investigation has been compiled in the form of geologic drawings and cross sections. These drawings and cross sections summarize information gathered during the installation of monitoring wells, geoprobe installation, permeability testing, synoptic and transient water level gauging events. Information gathered was also used to construct a hydrogeologic model of the site (Section 3.3.2.5). Geologic drawings appear in Appendix A as follows:

- Geologic Units in Contact With Refuse - Drawing No. 3
- Elevation of Top of Shallow Sands - Drawing No. 4
- Thickness of Shallow Sands - Drawing No. 5
- Elevation of Glacial Confining Unit (Unit 1F) - Drawing No. 6
- Thickness of Glacial Confining Unit (Unit 1F) - Drawing No. 7
- Elevation of Cretaceous Clay Surface (Unit 3) - Drawing No. 8
- Thickness of Cretaceous Clay (Unit 3) - Drawing No. 9
- Thickness of Top of Cretaceous Sand (Unit 5) - Drawing No. 11
- Cross Section Locations - Drawing No. 12
- Section A-A' - Drawing No. 13
- Section B-B' - Drawing No. 14
- Section C-C' - Drawing No. 15
- Section D-D' - Drawing No. 16
- Section E-E' - Drawing No. 17
- Section F-F' - Drawing No. 18
- Historic Drainage - Drawing No. 19
- Site Utilities and Sewer Plan - Drawing No. 20

The geologic cross sections were created by compiling boring log data collected during recent and past investigations. Monitoring wells used to construct the sections are shown on the cross sections along with their corresponding well screen intervals. These cross-sections also plot piezometric/potentiometric head measurements at each well screen for June 1997. Water level and piezometric head maps were generated for key hydrogeologic units for the June 1994 and June 1997 measurement periods. These data are presented in Appendix A as:

- Water Table Elevation, June 24, 1994 - Drawing No. 21
- Piezometric Heads in the Cretaceous Sand (Unit 5) - June 24, 1994 - Drawing No. 22
- Water Table Elevation, June 20, 1997 - Drawing No. 21
- Piezometric Heads in the Glacial/Reworked Cretaceous Sub-Aquifer (Unit 1i) - June 20, 1997 - Drawing No. 24
- Piezometric Head in the Cretaceous (Unit 4A), August 18, 1997 - Drawing No. 25
- Piezometric Head in the Cretaceous Sand (Unit 5), August 18, 1997 - Drawing No. 26

When considering the potential for the migration of chemical constituents in groundwater, these cross sections and drawings enable us to predict major flow regimes at the site.

The hydrogeology of Brookfield Avenue Landfill can be broken down into three distinct groundwater flow regimes: Shallow Recent/Glacial, Deep Glacial/Reworked, and the deeper Cretaceous aquifers. A schematic groundwater flow system is shown in Figure 3-11. Major geologic units playing a role in groundwater flow throughout the site have been grouped according to three distinct flow systems.

The Shallow Recent/Glacial flow system combines the interaction of:

- Fill Material: This unit consists primarily of household trash and construction debris. On the eastern portion of the landfill fill material has been covered with a clay cap which has been eroded away in certain sections of the landfill. This unit has a highly variable permeability and may allow leachate to seep into surficial bodies of water.

- Meadow Mat (Peat): Black Peat, trace to little silt and clay, trace fine sand, low to medium plasticity. This confining unit is discontinuous in nature and highly variable across the site.

- Recent Silt and Clay: Gray-Black Clay and Silt, trace fine sand, organic rich, medium to high plasticity. This confining unit is discontinuous in nature and highly variable across the site.

- Recent Sands: Light Gray to Black Sand, trace to little silt. This unit may act as a pathway for horizontal contaminant migration to surface water features or vertical migration to deeper glacial units when glaciolacustrine sediments are thin or absent. Recent sands have been found in lenses and appear to be discontinuous across the site.

- Shallow Glacial Sands: Moderate red-brown fine to coarse Sand, trace silt, trace to no clay moderate to well sorted. When encountered this unit is saturated suggesting that it is a significant pathway for groundwater flow. In the eastern portion of the site, shallow glacial sands are found with great frequency. In an area between Miles and Tanglewood Avenues, there is a 10 to 20 foot thick sequence of shallow glacial sands trending north south across the site which then follow Richmond Creek downstream. A shallow sand sequence is also found trending north to south along Abingdon Road near a historic stream bed. This may provide evidence of a glacial esker-type deposit or possibly reveal post-glacial fluvial deposition.

The Deep Glacial/Reworked flow system is comprised of:

- Glacial Till with Glaciolacustrine Clay/Silt: Moderate red-brown Silt and Clay, trace to some sand, trace to some gravel. This comprises the main confining unit of the deep Glacial flow system.
- Deep Glacial Sands: Moderate red-brown fine to coarse sand, trace to no clay, well to moderately sorted. This unit is a highly permeable aquifer within the deep Glacial flow system. This unit may be hydraulically connected to potentially contaminated groundwater in the southern portion of the landfill where glaciolacustrine clays or clayey glacial tills are absent.
- Glacial Till with Sand: Moderate red-brown sand some to and gravel, trace-little silt, trace to no clay. This is the main aquifer controlling flow in the deep Glacial flow system. This unit appears to be thickest in the north portion of the site where glacial scouring has cut deepest into the underlying cretaceous formations. In the southern portion of the site, the absence of the glaciolacustrine clay/glacial till aquitard may allow contamination to seep into the glacial till with sand unit. Beds of sandy glacial till tend to dip gently south to north and may be hydraulically connected to the deeper cretaceous flow system in local areas.
- Glacial Till with Glaciolacustrine Clay and Reworked Cretaceous Sediment: Moderate red-brown and gray silty sand or sand trace to with silt. This unit comprises the basal aquifer within the deep glacial flow system. It appears to have been deposited on top of the organic rich gray clay following the glacial scouring of that bed. The material appears to be reworked because it combines glacial sediments with the stratigraphically lower cretaceous sediment.

The Cretaceous flow system is comprised of:

- Cretaceous Clay, Organic Rich Dark Gray to Gray Clay: Trace to some silt, trace very fine sand, trace to with lignite, trace pyritic concretions, very thin lamination bedding, firm to stiff, medium to high plasticity, micaceous. This aquitard forms the base of the deep glacial flow system acting as a confining unit where present. In the northern portion of the site under Richmond Creek, this aquitard is absent due to glacial scouring. Glacial till and glacial till with sand has "filled-in" these locations where the organic rich dark clay has been eroded, creating possible pathways for the migration of contamination to the cretaceous flow system's aquifer formations.

the nature of this source of contamination and well as to determine levels and types of treatment that may be required.

3.5.1 Objectives

The objectives of this characterization are to:

- determine the composition of the leachate to develop a "fingerprint" or "signature" of contamination from this landfill. This will assist in determining the environmental impacts from this landfill rather than just the sum of other contamination sources (e.g., Fresh Kills Landfill, Stormwater runoff etc.).

- determine the volume generation rate and composition of the leachate to assist in evaluating whether leachate controls will be necessary and evaluate the feasibility of various leachate control systems.

3.5.2 Investigation Process

All leachate characterization activities were addressed during Phase I of the field investigation. The investigation included leachate sampling and mathematical modeling of leachate generation rates using the Hydrologic Evaluation Landfill Program (HELP) model.

3.5.2.1 Leachate Sampling

Two rounds of leachate samples were collected from wells screened within the landfill as well as leachate seep observed along the perimeter of the landfill. Round 1 samples were collected during May 1994. Round 2 samples were collected during May-June 1997.

Five leachate wells and 5 leachate seep sample locations were sampled for each round. The leachate wells were sampled in the same manner as the groundwater monitoring wells. Leachate seeps required a visual reconnaissance to determine the location of significant seeps and then the simple filling of sample containers from the flowing source of leachate. All samples were analyzed for VOA, Semi-VOA, TAL metals, PCB and Pesticides and a broad range of conventional parameters used as leachate indicators. The initial leachate parameter list is shown in Table 3-7. This list was made more focused in followup rounds of sampling.

3.5.2.2 HELP Modeling

Leachate from the Brookfield Avenue Landfill is produced when rainfall falls on the landfill surface, infiltrates into the ground and flows vertically downward through the waste. Leachate may also be produced when groundwater flowing from offsite comes into contact with the waste. As it passes through the waste, it is assumed to become contaminated. Water level data and the site groundwater flow model indicate that a groundwater mound has formed within the solid wastes. It is estimated that only a small amount of the regional groundwater passes into and out of the solid waste. Groundwater flowing through the solid waste is not a significant mechanism for leachate generation.

The amount of leachate produced at the Brookfield Avenue landfill was estimated using the EPA's Hydrologic Evaluation of Landfill Performance Model - Version III (HELP) (Schroeder etal, 1994). The HELP computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts various soil, weather and design data to account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage and lateral and vertical drainage. For the purpose of the HELP model, it was assumed that leachate is only generated by the infiltration of rainfall on the landfill.

To account for varying site conditions, the landfill was divided into six areas based on thickness of waste, slope, and the existence or lack of a cap. Soil data were selected based upon soil types as classified in boring logs. The capped portion of the landfill (Area B1) was assigned the properties of an uncompacted, weathered clay. The degree of vegetative cover was developed based upon field observation. The model was run for a five year span, using the default precipitation and weather data provided for the New York City area (1974-1978). The default precipitation data was selected because it was near the long term annual average (1962-1991) or 42.12 inches/yr. In fact, the period simulated was about 6 percent greater (44.79 inches/yr.) than the long term annual precipitation average, hence the prediction should be somewhat greater than average.

A summary of the results of the HELP model are given in Table 3-8. A complete summary of the model input and output is found in Appendix F. The average annual infiltration to and leachate generated from the waste containing areas of the site was estimated to be approximately 95,000 gallons/day or 22 percent of annual rainfall, which is typical for uncapped landfills in the New York City Metropolitan area.

The primary purpose of the HELP model is to assist on the comparison of design alternatives as judged by their water balances. Therefore, caution should be used when considering the HELP model calculated rate of leachate generation (its generally considered an average) as a design condition. Leachate generation rates are strongly a function of conditions and therefore, highly transient.

3.6 Landfill Gas Characterization

Landfill gas is formed as a byproduct of waste decomposition and volatilization of chemicals within the waste mass. Presumptive remedial measures require landfill gases to be managed for as long as they are expected to be generated.

3.6.1 Objectives

The objectives of this characterization were to:

- determine the composition of landfill gases
- determine the landfill gas emission rate and the routes of gas migration (i.e., subsurface soil migration, passive landfill gas vents, landfill surface fluxes)
- determine the extent of subsurface migration of landfill gases

- determine whether any landfill gases are accumulating in nearby residential basements as a result of the subsurface soil migration of landfill gas
- estimate the rate of landfill gas generation.

3.6.2 Walkover Screening Survey

As per the guidance provided by the EPA user's guide (EAP/600/8-86/008, Feb. 1986) an initial emissions survey was conducted. The emissions survey was the basis for locating flux box sampling stations. The fill area was subdivided using 200-foot distances between grid stations. A flame ionization organic vapor analyzer (OVA) and a photoionization detector (PID) were used to measure the concentration of ground-level total hydrocarbons at each grid node. The OVA and PID were used to differentiate between total and non-methane hydrocarbons. One hundred and thirty (130) nodes were tested.

The results of this initial emission survey were plotted. Hot spots and/or crevasses were identified to select surface emission flux box sampling stations. The landfill surface was also segregated into zones representing ranges of ground level hydrocarbon concentrations measured during the initial emission survey. Flux box sampling stations were located in each zone to determine emissions from typical cover and from point sources such as crevasses and hot spots.

3.6.3 Residential Basement Screening

Landfill gas preferentially moves horizontally in undisturbed soils. Landfill gas moves approximately eight feet horizontally for every one vertical foot of solid waste. Using this approximation, the potential extent of landfill gas influence from the Brookfield Avenue Landfill was estimated at 350 feet from the edge of the fill mass.

Using this simple guide, off-site migration of methane gas from the landfill was a potential concern in residential basements along Arthur Kill Road (near the south perimeter of the landfill) and Colon Avenue (where the wastewater force main travels beneath the street to the Eltingville Pump Station.) In addition to the landfill perimeter soil gas monitoring, selected home basements were tested for combustible levels of methane. A community survey performed in June 1993, indicated that of the 98 responses to the survey, 60 homes were identified as having basements. Of these, six (6) were located on Arthur Kill Road and four (4) were located on Colon Avenue. The basements of these ten homes were tested with a Combustible Gas Indicator. In addition, homes on Colon Avenue within one block of Arthur Kill Road were notified again and advised that basement air testing was available. A total of 25 homes were screened once a month for three months (December, 1993, February, 1994, and March 1994).

3.6.4 Temporary Perimeter Soil Gas Probes

Temporary soil gas probes were located around the perimeter of the landfill to identify appropriate locations for the permanent soil gas monitoring wells. This screening analysis consisted of soil gas monitoring using 65 temporary gas probes which were driven to a soil depth of 18 inches. 50 temporary probes were spaced at 200-foot intervals along with the southern, eastern, and western site perimeter, and were spaced at 600-foot intervals along the northern site perimeter approximately 25 feet outside of the waste mass. The northern perimeter was not investigated as

3.6.6 Landfill Gas Probes

To adequately evaluate appropriate gas treatment technologies during the feasibility study, four gas samples from within the landfill (from existing leachate wells) were collected and analyzed. Leachate gas sampling was completed during Phase II sampling.

The original plan was to collect the four landfill gas samples from existing leachate monitoring wells. However, due to unseasonably heavy rains during the winter of 1997-1998, the entire screen zone of the targeted wells were saturated and gas samples could not be drawn from the leachate wells. As a result, CDM had to use temporary soil gas sampling probes in order to collect the samples from the leachate wells.

A total of four gas probes were used, the locations selected for each probe was based on the original leachate well designated for sampling which included LW-2, LW-3, LW-4 and LW-5. Each probe was driven approximately five feet into the landfill within 2 to 10 feet of its respective leachate well designation. After driving, a Teflon tube was placed within the probe so that a sample would be drawn at the base of the probe through the Teflon tubing. A vacuum pump was used to purge each probe and a landfill gas meter was used to monitor the purge gas to ensure a representative sample was collected and that collection of atmospheric air would be avoided.

After measurements of CH_4, CO_2 and O_2 had stabilized at levels typical of pure landfill gas, a glass lined Summa canister was connected to the Teflon tubing and a grab sample collected. After collecting the Summa canister sample, a sorbent tube for hydrogen cyanide was connected in the tubing and a sample pump used to draw a sample through the tube. Air samples were analyzed for TO-14 volatile organics, hydrogen sulfide, hydrogen cyanide, mercaptans, carbon dioxide and methane.

3.6.7 Flux Box Sampling

Measurements of gas emissions through the landfill surface were performed using a flux box at ten on-site sampling stations. The objectives of the flux box sampling were to:

- quantity the surface emissions from the landfill; and
- characterize the composition of the landfill gas emissions.

Eight of the ten flux-box sampling points were located throughout the landfill to sample representative low, medium, and high surface emissions points. These low, medium, and high surface emission points were identified during the initial emissions survey. The two remaining sampling points were located on visible crevices or surface fractures.

The flux box air samples were analyzed for TO-14 volatile organics, hydrogen sulfide, hydrogen cyanide, mercaptans and methane. The analyte list for TO-14 volatile organics is presented in the QAPP. SUMMA canisters were used to collect the air samples for TO-14 volatile organics and methane. These samples were collected via sub-atmosphere sampling using an evacuated canister with a critical orifice. Methane was analyzed from the SUMMA canister samples by ASTM method D3416. Air samples for hydrogen sulfide and methyl mercaptan were collected using tedlar bags. Analysis for hydrogen sulfide and methyl mercaptan was performed using federal test methods 15 and surface air infiltration is reduced or eliminated. Landfill gas generation rate estimates following capping will be used, in combination with any collected field data, to assess the feasibility and provide design parameters for the design of the gas collection system.

The following data were used for the Brookfield Avenue LFGAS model:

- Landfill dimensions and geometry including slope, depth and length to width ratio
- Expected landfill temperature and moisture content
- Quantity and characteristics of waste received by Brookfield during its operational history

The Brookfield site was divided into five different parcels as shown in Figure 3-12. The parcels were chosen based on the time periods over which they were actively filled. The period of filling was estimated from historical aerial photos. The time periods for each parcel are as follows:

Parcel	Period of Active Filling
A	1966-1974
B	1974-1978
C	1978-1980
D	1966-1974
E	1974-1978

LFGAS was run separately for each parcel and the results were combined to obtain an overall estimate of landfill gas production for the landfill.

The first set of inputs for LFGAS is the basic waste receipt information. The volume of solid waste was obtained from estimates based on site maps showing the elevation and areas of the solid waste. LFGAS requires that the input of waste receipts be entered in tons. The density range for landfills which are predominantly municipal waste and approximately 20 years old is 1000-1200 lb/ft^3. A value of 1,000 lb/ft^3 was assumed for this estimate. With this information, total waste quantities were calculated for each parcel. The LFGAS option used for this analysis requires that the waste quantities be entered for each year of a landfill's lifetime. Therefore, annual waste quantities were determined for each year that a parcel was active. It was assumed that the growth rate for waste generation over the active period of the parcels was small and thus the total amount of waste over the life of each parcel was distributed evenly over the years it was active. A portion of the waste is located beneath the water table. This waste was not included in the totals since under conditions of complete saturation, gas generation rates would be negligible. These annual waste quantities for each parcel are as follows: