POST CLOSURE MANAGEMENT OF A HAZARDOUS WASTE LANDFILL AT THE MASSACHUSETTS MILITARY RESERVATION MAIN BASE LANDFILL

by

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B.S., Civil and Environmental Engineering
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ABSTRACT

This thesis details the development of a post-closure management plan for a hazardous waste landfill. The cover system designed by Elias (1996) for the 1951 cell at the Massachusetts Military Reservation (MMR) located on Cape Cod, Massachusetts was used as the basis for the plan. The proposed plan satisfies the requirements for the closure/post-closure management of landfills stipulated by the state of Massachusetts. The purpose of the plan is to ensure that the cell will not contribute any further contamination to the aquifer, and to assess the cap and geomembrane performance. The management plan specifies a monitoring program for ground and surface water as well as air quality. Three monitoring wells, along with several pre-existing wells, will be used to determine if the landfill cell is contributing contamination to the underlying aquifer. To satisfy regulations, one additional gas probe is also specified in the vicinity of the cell to monitor air quality. In addition, the plan details a maintenance program, which outlines an inspection schedule, instructions as to which parameters have to be monitored and corrective actions that might be undertaken if problems are encountered.

In addition to the post-closure management plan, the thesis also discusses possibilities for post-closure land use and examines geomembrane durability. It was determined, that with an effective implementation of the post-closure management plan, the landfill cell should not contribute any further contamination to the aquifer and geomembrane durability in the cap system should be assured. In addition, it was concluded that opportunities for future land use appear minimal. A new cover system would have to be designed to sustain the load of any development (which could be cost-inhibitive) and further, the public's full acceptance of a development over a hazardous waste landfill seems, in the author's opinion, to be unlikely.

This thesis is submitted in partial fulfillment of the requirements for the Master of Engineering degree in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT) and forms one part of a major group report focusing on groundwater contamination and remediation at the Main Base Landfill. The group report included a model of groundwater flow in the area, an investigation into the source of PCE and TCE, an investigation into feasibility of bioremediation and the application of horizontal wells for remediation activities in the area.

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1. INTRODUCTION

1.1 Problem

This thesis presents the results of a research project dealing with the post-closure management of a hazardous waste landfill at the Massachusetts Military Reservation (MMR) located on Cape Cod, Massachusetts. The cover system designed by Elias (1996) for the 1951 cell was used as the basis for this plan. The purpose of the work was to develop a plan that would satisfy the closure/post-closure requirements for a landfill site mandated by the state of Massachusetts that is to be effective in service for at least thirty years. The thesis also includes alternatives for post-closure land use and discusses geomembrane durability. It is submitted in partial fulfillment of the requirements for the Master of Engineering degree in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT) and forms one part of a major group report focusing on groundwater contamination and remediation at the Main Base Landfill (Haghseta et al., 1997).

The landfill area is located approximately 2 miles from the western and southern borders of the Massachusetts Military Reservation (MMR). The landfill covers approximately 100 acres and is bounded by Turpentine and Frank Perkins Roads to the east and west and Herbert Road and Connery Avenue to the north and south, respectively. The landfill which was operated since the 1940s, ended its operations in 1984. Currently, all the waste generated at the MMR is sent to a transfer station to be disposed of at the SEMASS incinerator in Rochester, MA.

While operational, disposal in the landfill occurred in five distinctive cells and a natural kettle hole, each one named by the last year of its operation. The plume emanating from the site has been termed the LF-1 plume. The major contaminants of concern are trichloroethylene (TCE) and tetrachloroethylene (PCE). In efforts to contain future groundwater contamination from the landfill, the 1970, Post-1970 and the Kettle Hole cell areas were capped. Recent investigations at the site have demonstrated the following concerns: possibility of contaminated groundwater entering public drinking well supplies, effect of the contaminated groundwater reaching Buzzards Bay and possible cancer risks from the neighboring population's exposure to contaminated groundwater (CDM, 1996).

1.2 Objectives

The main objective of the work presented in this thesis was to develop a post-closure management plan that will ensure that the 1951 cell does not contribute any further contamination to the groundwater. In addition, the plan was to be formulated so as to help assess the cap and geomembrane performance of the 1951 cover system designed by Elias (1996). The details of this post-closure management plan are also presented in a group report that included a model of groundwater flow in the area, an investigation into the source of PCE and TCE, feasibility of bioremediation and the application of horizontal wells for remediation activities (Haghseta et al., 1997).

Because in the future there may exist a need to develop the covered land at the LF-1 site, alternatives available for post-closure land use of a capped hazardous waste landfill were also investigated. Also, since geomembrane durability is of great concern to engineers, an investigation into the behavior of geomembranes was also undertaken during the course of this work and used to estimate the durability of the geomembranes used in the design of the cover system for the 1951 cell.

1.3 Scope

This report is structured as follows: Chapter 2 provides background information on the MMR and the Main Base Landfill. Chapter 3 details the proposed post-closure management plan. This chapter includes a section for groundwater, air and surface water quality monitoring. In addition, a cover maintenance program is detailed. Chapter 4 examines alternatives for post-closure land use. Chapter 5 investigates the factors used in determining geomembrane durability. An overview of geomembranes , degradation processes, synergistic effects and predictive methods are presented here. Finally, chapter 7 provides conclusions from this thesis.

2. SITE DESCRIPTION

2.1 Massachusetts Military Reservation

The Massachusetts Military Reservation (MMR) is located in the upper western portion of Cape Cod, Massachusetts and occupies approximately 22,000 acres within the towns of Bourne, Mashpee and Sandwich, and adjacent to the town of Falmouth, Figure 2-1.

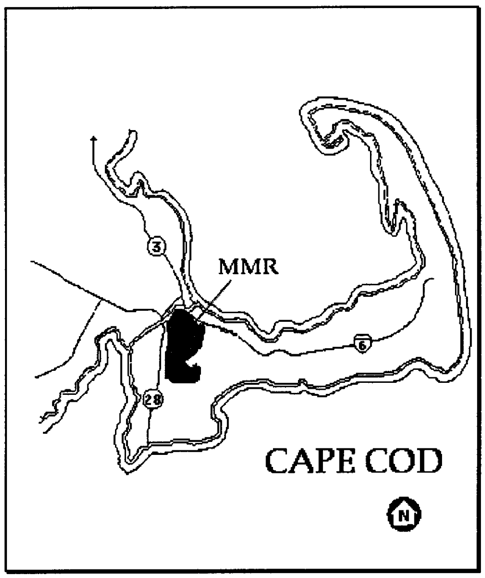


Figure 2-1 MMR Site Location Map

Military use of portions of MMR began in 1911, the bulk of which has occurred since 1935. Facilities at MMR are operated by the Air National Guard, Army National Guard (ARNG), U.S. Air Force (USAF), U.S. Coast Guard (USCG) and Veterans Administration (VA).

The MMR is organized into four principal areas: the Range Maneuver and Impact Area, the Cantonment Area, the Massachusetts National Cemetery and the Cape Cod Air Force Station, Figure 2-2. The Range Maneuver and Impact Area occupies approximately

14,000 acres of the northern portion of the base and is used for training and maneuvers. The Cantonment Area, the most active area of MMR, occupies approximately 5,000 acres of the southern portion of the base and includes the Otis Air Base facilities and flightline area. The Massachusetts National Cemetery occupies approximately 750 acres along the western edge of the base and includes the cemetery and its support facilities. The Cape Cod Air Force Station occupies approximately 87 acres of the Range Maneuver and Impact Area .

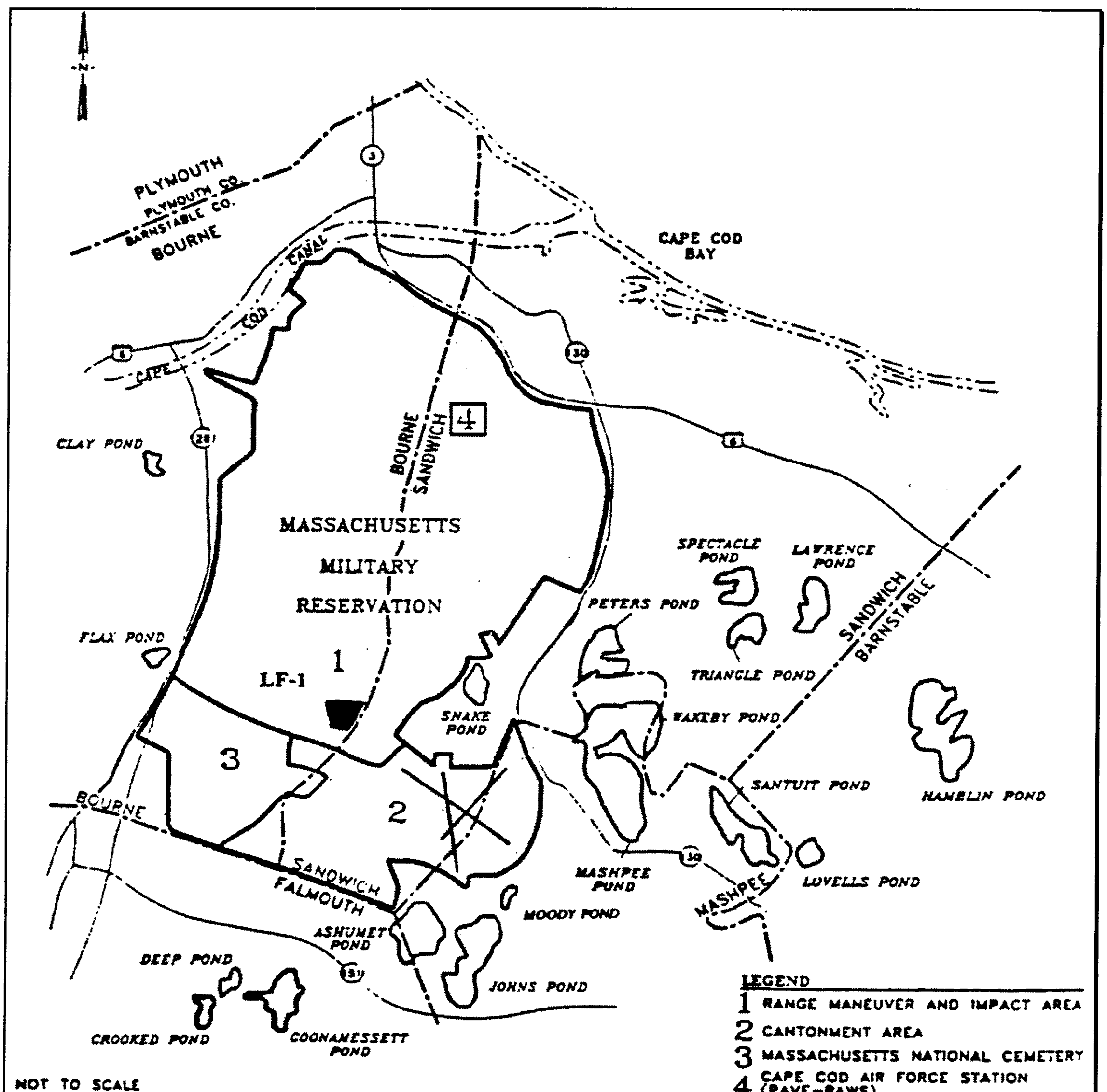


Figure 2-2 LF-1 Location Inside the MMR

2.2 Environmental Setting

2.2.1 Geology

The major surficial deposits of the LF-1 study area are the Mashpee Pitted Plain (MPP), the Buzzards Bay Moraine (BBM) and the Buzzards Bay Outwash (BBO). Other significant surficial deposits include lake deposits, lodgment glacial till and glaciolacustrine sediments. The thickness of unconsolidated deposits ranges from approximately 200 to 500 feet beneath the BBM.

2.2.2 Climate and Surface Water Hydrology

The climate at MMR is described as humid continental. Precipitation is fairly evenly distributed throughout the year, with the least amount of rainfall typically occurring in June. The average annual precipitation is 46 inches and the average monthly precipitation is 4 inches.

The MPP and BBM areas are dotted with irregular hills, depressions and kettle holes, some of which extend below the water table. Drainage for the most part is irregular with a few intermittent streams. Due to the porous nature of the soils, infiltration is rapid and therefore, a mature drainage system has not been developed. Net annual recharge is estimated to be 21 inches, or nearly 50 % of the annual precipitation.

2.2.3 Hydrogeology at the Main Base Landfill

A single groundwater flow system underlies western Cape Cod, including the MMR. Aquifer recharge in the Main Base Landfill area is provided entirely through the infiltration of precipitation to the water table. The aquifer is unconfined and ranges from 50 to 175 feet in thickness. The bottom of the aquifer is noted by a transition from sand and gravel to very fine sand, silt and/or clay. The aquifer in the vicinity of the LF-1 area is heterogeneous and the groundwater flow is west.

2.3 Main Base Landfill

The Main Base Landfill (LF-1) is located in the southern portion of the Range Maneuver and Impact Area, approximately 2 miles from the western and southern borders of MMR. The landfill occupies approximately 100 acres of open to heavily wooded terrain and is bounded by Frank Perkins Road to the west, Herbert Road to the north, Turpentine Road to the east and Connery Road to the south.

LF-1 has operated as the primary solid waste facility at MMR since 1944. Unregulated disposal activities were terminated in 1984. Wastes were historically deposited in five distinct cells and one natural kettle hole, Figure 2-3. The cells are designated by the year representing the last year of waste disposal in that particular cell. The six disposal cells are the 1947, 1951, 1957, 1970, Post-1970 and the Kettle Hole, respectively.

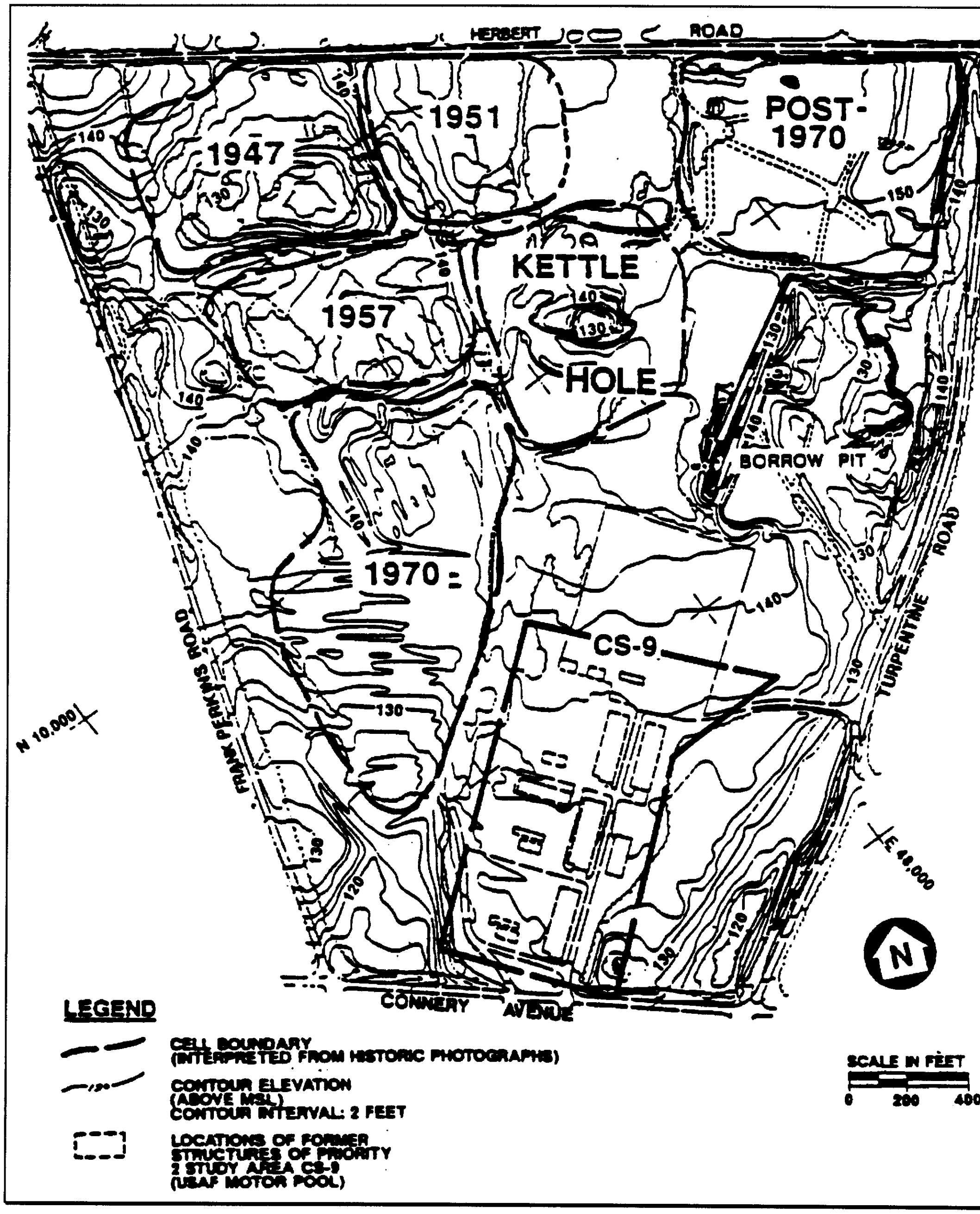


Figure 2-3 LF-1 Disposal Cell Location Map

Wastes deposited in the cells are believed to include general refuse, fuel storage tank sludge, herbicides, solvents, transformer oils, fire extinguisher fluids, blank small arms ammunition, paints, paint thinners, batteries, dichlorodiphenyltrichloroethane (DDT) powder, hospital waste, municipal sewage sludge, coal fly ash and possibly live ordnance.

These wastes were deposited using a linear trench method. The trenches were approximately 30 feet deep, 50 feet wide and 500 feet long. The common practice was to cover landfilled material with approximately 2 feet of on-site sand and gravel. Magnetic resonance was used to determine disposal boundaries. Currently, all the waste generated at the MMR is sent to a transfer station to be disposed at the SEMASS incinerator in Rochester, MA.

The landfill was identified as a potential contaminant source in 1979, when a drinking water well downgradient of the landfill tested positive for levels of volatile organic carbon (VOC) contamination that exceeded drinking water standards. At present, the contaminant plume begins at a depth of 40 feet below the landfill and extends 15,000 feet to the southwest with a maximum width of 5,000 feet. The main VOCs of concern are trichloroethylene (TCE) and tetrachloroethylene (PCE). In addition, a soil gas survey performed within the landfill boundaries detected VOCs in near surface soil vapor throughout the Post-1970 cell, in portions of the 1957 and 1970 cells, and in the kettle hole. As part of a remediation effort, closure activities for the 1970, Post-1970 and the Kettle Hole were performed.

2.3.1 1951 Cell and the NWOU

The 1951 cell was grouped together with the 1957 and 1947 cells and termed the Northwest Operable Unit (NWOU). Remediation efforts for the landfill did not include the closure of the NWOU, instead a groundwater monitoring program for the cells was implemented. The cell covers approximately 10 acres and has a relatively flat terrain. Test-pits in the 1951 cell revealed a cell cross-section of approximately 2 feet of native soil overlying approximately 8 feet of burnfill and miscellaneous debris underlain by clean sand.

3. POST-CLOSURE MANAGEMENT PLAN

This section proposes to develop a post-closure management plan for the cover system designed for the 1951 cell by Elias (1996), which will include a ground and surface water monitoring plan, a program for air quality monitoring and a maintenance plan. This management plan will ensure the integrity of the cover system for an extended period of time, and will diminish the possibility of the capped cell contributing to further groundwater contamination.

The Massachusetts Solid Waste Management Regulations (310 CMR 19.142) require the post-closure monitoring period for landfill closure to extend to a minimum of 30 years. Therefore, this plan will include the necessary elements of a post-closure management plan for the 1951 capped cell for a period of 30 years, to be effective when all the closure requirements have been met. This plan will satisfy all requirements in 310 CMR 19.000. In what follows, a plan for groundwater, air quality and surface water monitoring are first presented. Then, a brief explanation of the cover design is given along with maintenance activities for the cover system. Finally, a plan for facility records and the submittal of reports is specified.

3.1 Groundwater Monitoring

Groundwater monitoring is necessary to determine if the capped landfill is still contributing contaminants to the aquifer and to ensure that all regulatory standards are being met. A groundwater monitoring program should include consistent sampling and analysis procedures designed to ensure monitoring of the groundwater quality at a number of sampling locations (McBean, 1995). In this section, a description of the groundwater monitoring plan for the 1951 cell will be presented.

3.1.1 Well Locations

Massachusetts Solid Waste Management Regulations (310 CMR 19.118) require a minimum of one monitoring well, or cluster of wells, located hydraulically upgradient (for background data) and a minimum of three monitoring wells, or cluster of wells, hydraulically downgradient, and to be installed within 150 meters of filled areas or at the property boundary. The reason for requiring three monitoring wells is to account for variances at a particular site. Landfill designers are invited to use "engineering judgment" in placing the monitoring wells in order to gather a representative sample of groundwater to assess any possible contamination. In addition, 310 CMR 30.663 (2) specifies that if a facility contains more than one regulated unit, separate groundwater monitoring systems shall not be required. Therefore, the final plan could include already present monitoring wells that have been installed for other purposes. The major factors that influence monitoring well location include chemical characteristics of the contaminants expected to seep into the aquifer (this item is waste specific), the design of the landfill (i.e., whether or not the landfill is lined or unlined, this item is landfill design specific), and the hydrogeological characteristics of the site (this item is site specific) (Bagchi, 1990).

To determine the location of the necessary monitoring wells, a preliminary analysis of a potential plume emanating from the LF-1 NWOU study area, which was performed by Stone & Webster, was used (Stone & Webster, 1996a). This analysis provided a site-specific basis for placement of the monitoring wells. Stone & Webster utilized the USGS Modflow hydrogeologic model of the MMR to simulate the directions, depths and lateral extent of a hypothetical plume emanating from the NWOU (Stone & Webster, 1996a). The MMR model is a three-dimensional finite-difference model based on equidimensional cells measuring 660 feet to a side.

A particle-tracking module (Modpath) was used to simulate the hypothetical plume. Two simulations were generated, one that assumed a single cell source and one that assumed a triple cell source. The true source area could not be entirely defined by the single cell simulation, thus the triple cell simulation was generated and used as the basis for the placement of borings/monitoring wells for the Remedial Investigation (RI) (Stone & Webster, 1996a). Figures 3-1, 3-2 and 3-3 show the results for the single cell, triple cell and the vertical profile map of the simulated plume, respectively.

Figure 3-1 Simulation Of A Hypothetical Plume Using A Single Cell Model (Stone & Webster, 1996a)

Figure 3-2 Simulation Of A Hypothetical Plume Using A Triple Cell Model (Stone & Webster, 1996a)

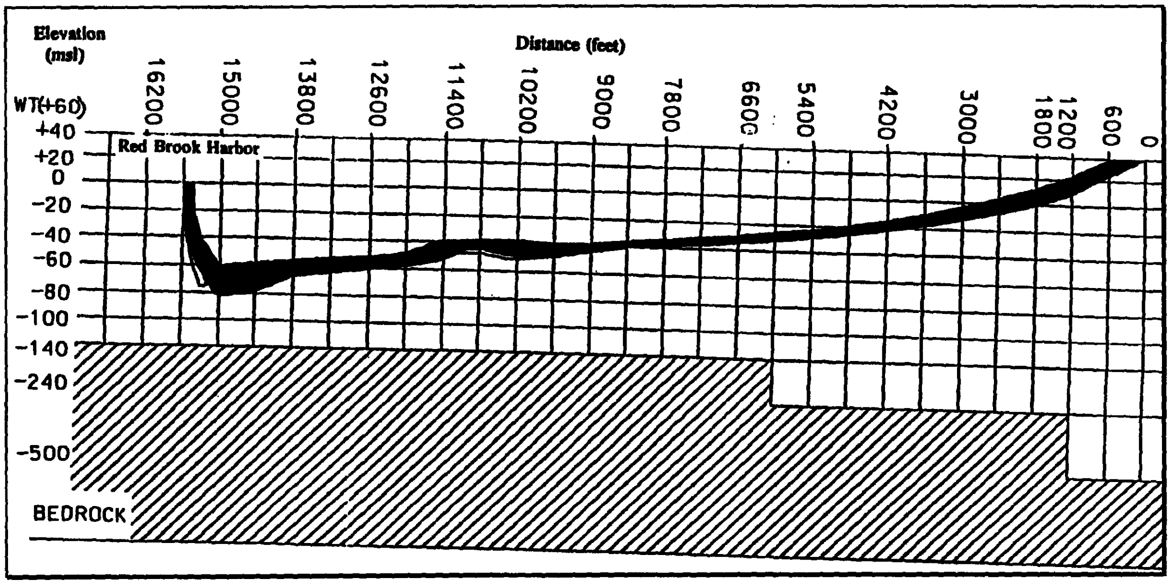


Figure 3-3 Vertical Profile Map For The Triple Cell Simulation (Stone & Webster, 1996a)

This model was used as the basis for determining the location of additional monitoring wells. The aquifer in the vicinity of the LF-1 study area is unconfined and heterogeneous. It ranges from 50 to 175 feet in thickness and is noted by a transition from sand and gravel to very fine sand, silt and/or clay (Stone & Webster, 1996a). Hydraulic conductivities for fine to medium sands within the aquifer are approximately 200 feet per day and for the coarse sand with a gravel fraction are up to approximately 300 feet per day (Stone & Webster, 1996a). As a result of the Stone & Webster Remedial Investigation, Well Fence No. N1.2 was built 1,650 feet west of existing Well Fence No. 1.1. Figure 3-4 shows the location of these two well fences. This groundwater monitoring plan proposes to make use of these two well fences in its monitoring and sampling plan. The use of these existing wells will be cost beneficial and will minimize further intrusion of the aquifer around the landfill area due to construction practices.

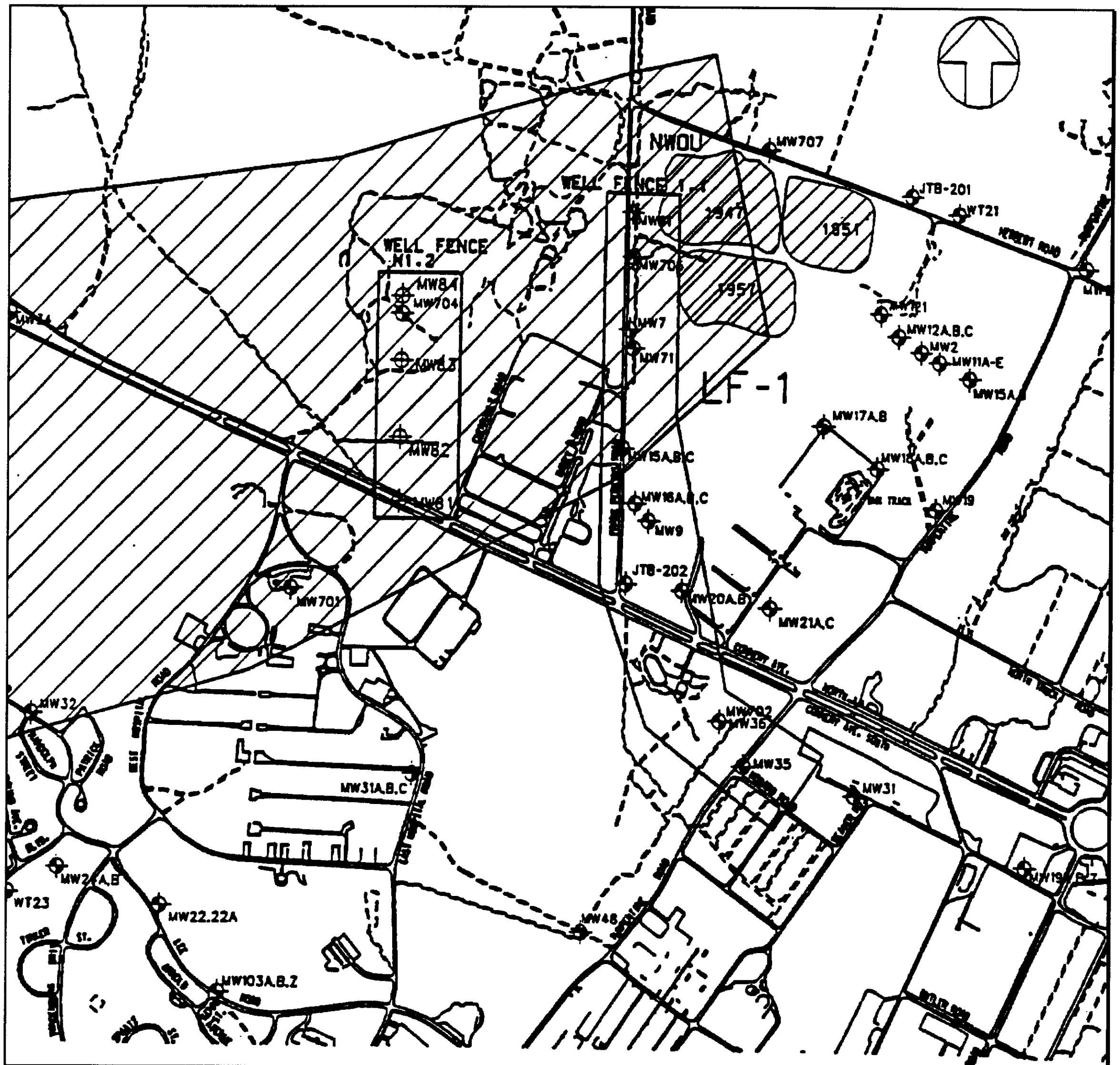


Figure 3-4 Location of Well Fence No. N1.2 and Well Fence No. 1.1 (Stone & Webster, 1996a)

Besides these well fences, the construction of three monitoring wells in the vicinity of the 1951 cell is proposed. Figure 3-5 presents groundwater flowlines and water table elevations in the LF-1 area. From this information, it can be noted that groundwater flow from the NWOU is west. For this reason, the proposed three monitoring wells will be placed at the boundary between the 1947 cell and the 1951 cell. Modeling the cell as a square with 624 feet to a side, one monitoring well will be located in each corner and one in the middle, making the effective distance 208 feet. Figure 3-6 presents the location of these wells along with the existing wells that are to be incorporated into the monitoring program. In addition, monitoring well #5 (MW-5) located in the northeast portion of the 1957 cell will be used. Details on the design of the monitoring wells, such as their depth and screen intervals, are presented in section 3.1.2. These wells must satisfy the design requirements stipulated by Massachusetts law and be installed by a person licensed under Well Driller Regulations, 313 CMR 3.00.

For background data (i.e. the upgradient well), currently installed monitoring well # 10 (not shown on map) will be used.

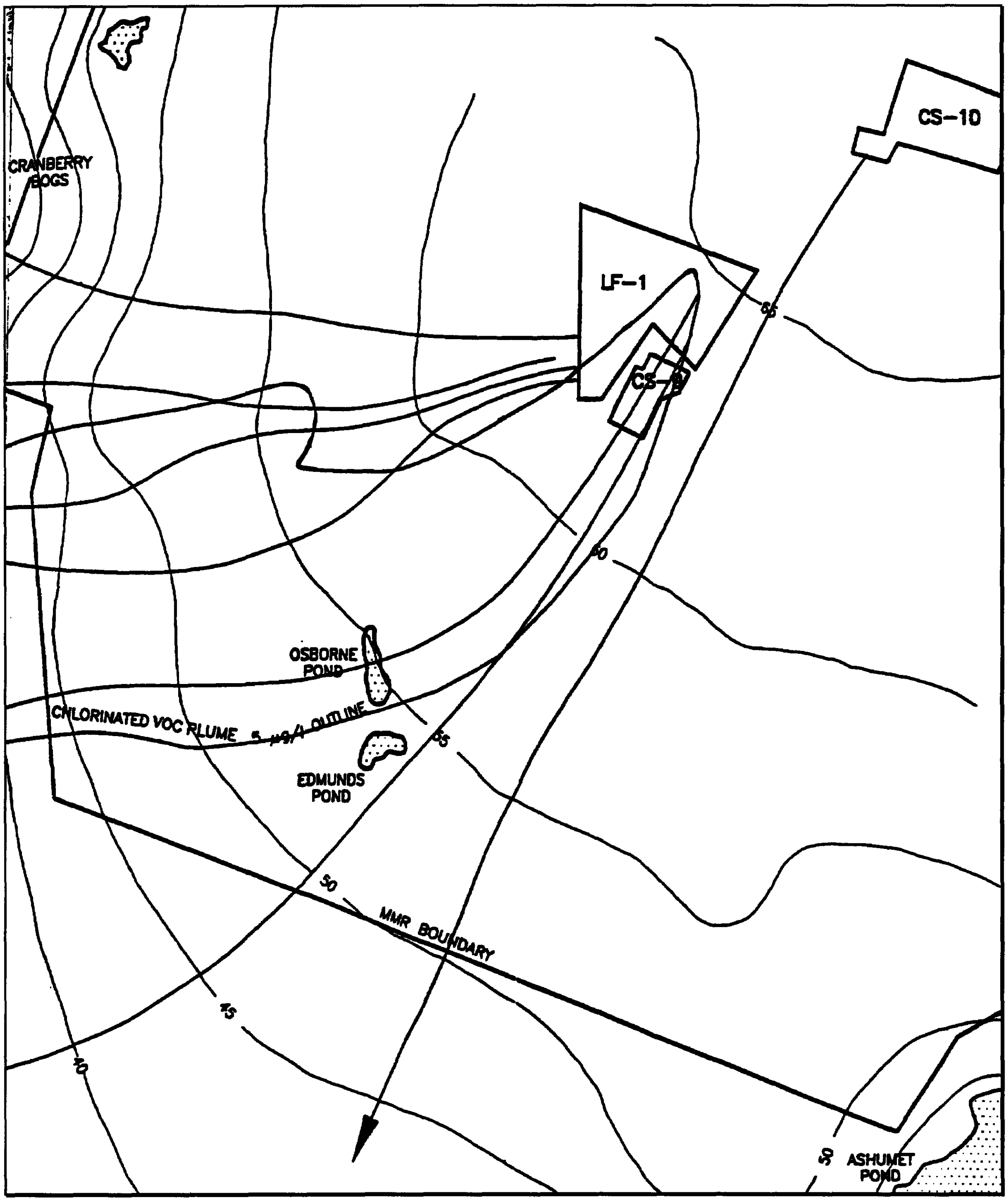


Figure 3-5 Water Table Elevations and Flowlines in the LF-1 Area (Stone & Webster, 1996a)

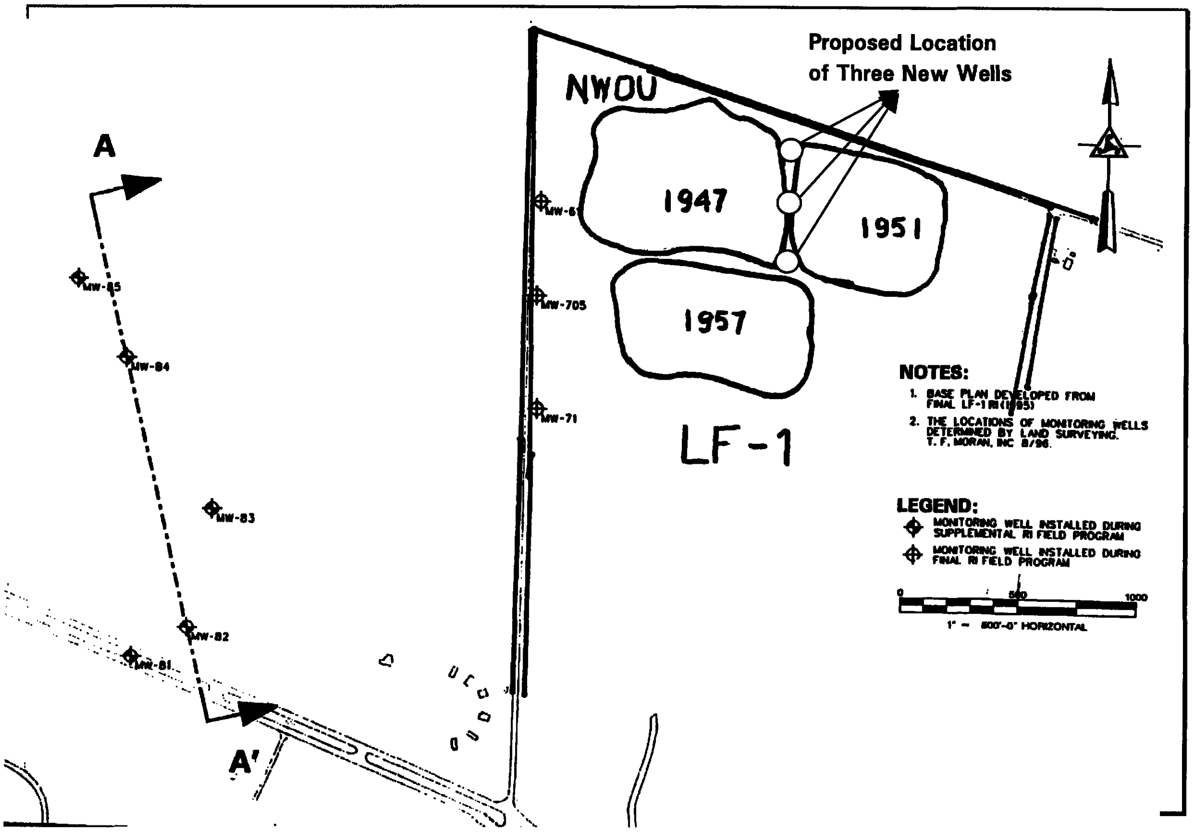


Figure 3-6 Groundwater Monitoring Wells for Post-Closure Monitoring (Stone & Webster, 1996a)

3.1.2 Design of Wells

Since the monitoring wells are to be placed very close to the potential pollutant source, their screened depth should not be too deep so as to allow for the detection of any contaminant leaching from the cell. Figure 3-3 indicates that the expected depth of the hypothetical plume near the source is approximately +60 to +40 feet (with the water table defined at +60 feet). The LF-1 area is defined at a distance equal to 0 feet. Thus, the screened length needs to be high to allow the determination of the presence/absence of potential groundwater contamination at each well.

Preliminary specifications for the three monitoring wells are as follows:

- Elevation to Top of PVC Riser : 138 feet
- Ground Surface Elevation: 135 feet
- Groundwater elevation (estimated): 62.1 - 62.4 feet
- Depth to bottom of screen: 145 below ground surface (bgs)
- Screen length: 80 ft

Final specifications will be determined at the time of construction to account for any variability. Figure 3-7 shows a schematic representation of the proposed monitoring well design. All wells should be cased and locked. Monitoring wells should be constructed of 2-inch, Schedule 40 polyvinyl chloride (PVC) with a continuously slotted screen.

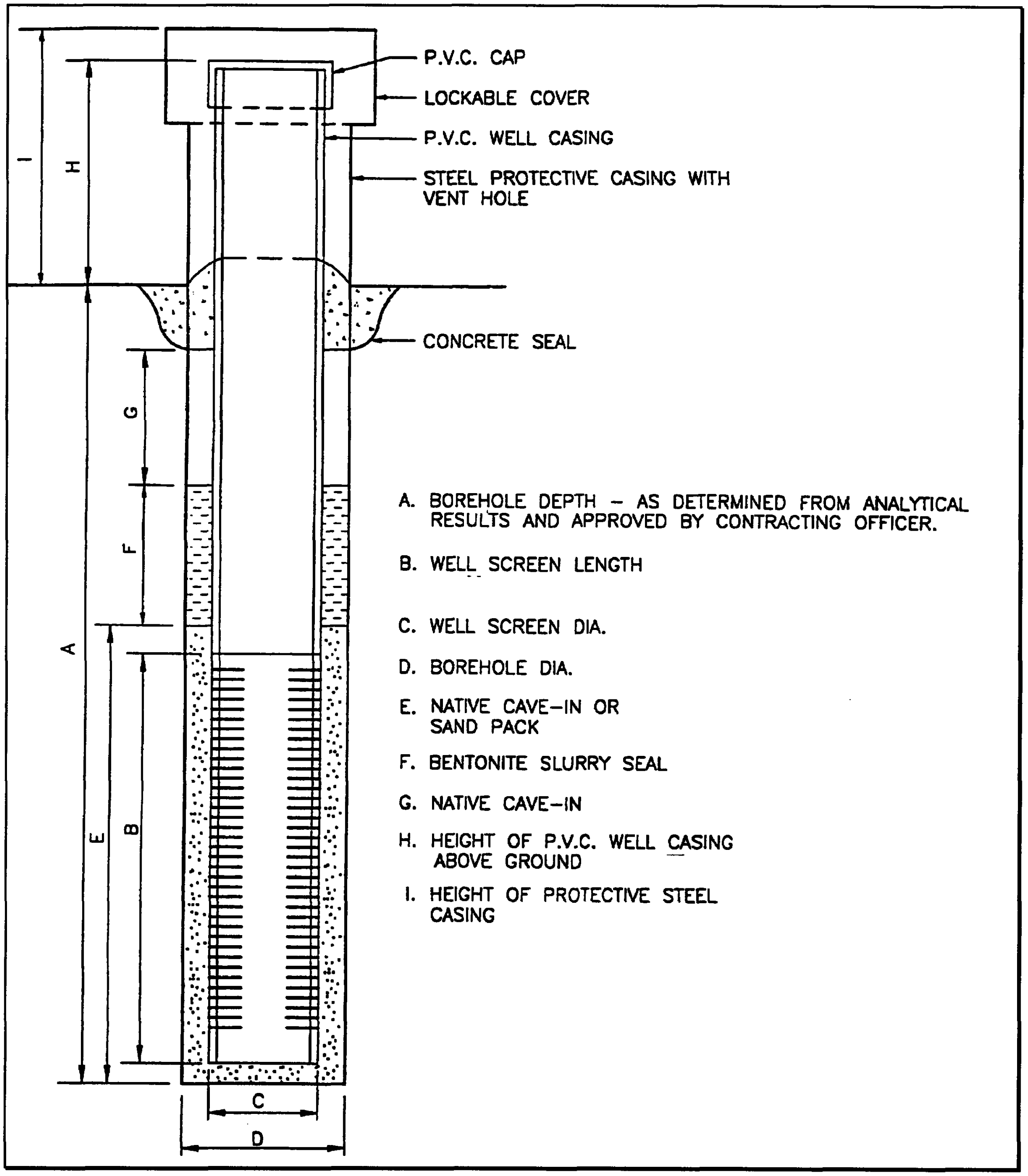


Figure 3-7 Schematic Representation Of a Monitoring Well (ABB Environmental Services, 1993b)

3.1.3 Sampling Plan

Massachusetts Solid Waste Management Regulations (310 CMR 19.132) require background water quality data to be determined using a minimum of four quarterly rounds of samples. In addition, 310 CMR 19.132 (1)(d) requires semiannual monitoring and sampling. Each time a sample is collected, the groundwater elevation and the total well depth must also be recorded.

To ensure proper groundwater quality, all samples should be analyzed for the parameters presented in Table 3-1, as specified in 310 CMR 19.132 (h). Site specific parameters are also included. These parameters were identified in Stone & Webster's RI, 1996a as site-specific parameters that have concentration levels higher than their natural background concentration. Stone & Webster's RI also demonstrated that the NWOU was a source of iron and manganese but not of VOCs. However, analytical results from the same RI concluded that the risk levels associated with the leaching of iron and manganese were minimal and that the 1951 cell should not pose an immediate threat to the groundwater quality of the aquifer. Nevertheless, this groundwater program is necessary to ensure that the cell does not contribute any further contamination over the required monitoring period.

Table 3-1 Groundwater Monitoring Parameters

Groundwater Monitored Parameters
Indicator Parameters:
pH (in situ)
Alkalinity
Temperature (in situ)
Specific Conductance (in situ)
Nitrate Nitrogen (as Nitrogen)
Total Dissolved Solids
Chloride
Iron
Manganese
Sulfate
Chemical Oxygen Demand
Dissolved Oxygen
Inorganics (EPA Methods 200.7 and 206.2):
Arsenic
Barium
Cadmium
Chromium
Copper
Cyanide
Lead
Mercury
Selenium
Silver
Zinc
VOCs using EPA Method 502.2
EDB using EPA Method 504.1
Explosives (nitroaromatics) using the HPLC Method
All compounds in EPA Method 8260[1]
Site Specific:
Aluminum
Beryllium
Calcium
Cobalt
Nickel
Potassium
Sodium
Thallium
Vanadium

[1] Method 8260 is detailed in the EPA Publication SW-846, entitled *Test Methods for Evaluating Solid Waste*.

Prior to sampling each well, between three and five well volumes of groundwater will be purged from the wells and a minimum of three consecutive pH, temperature, specific conductance and turbidity measurements of the groundwater will be obtained. These parameters' measurements will be used to determine if fresh formation water has entered the well (Stone & Webster, 1996a). After three consecutive parameter measurements have stabilized within a 10 percent variance, a groundwater sample can be collected. A minimum of four samples from each well will be collected.

All equipment in the wells shall only be used for monitoring purposes and a proper decontamination procedure for used devices must be followed. A proper sample identification system, sample handling, proper documentation and chain-of custody program will be developed at the time the monitoring program is set to start.

Groundwater samples will be collected using a submersible pump. To insure proper sample quality, trip blanks, matrix spike/matrix spike duplicates and source blanks will be generated at a frequency to be determined when the specific sampling plan is developed. Finally, all sampling and analytical procedures will be in accordance with Hazardous Waste Remedial Action Program documents DOE/HWP-65/R1 "Requirements for Quality Control of Analytical Data," DOE/HWP-69/R1 "Quality Control Requirements for Field Methods" and DOE/HWP-100 "Standard Operating Procedures for Site Characterization."

Analytical results will be submitted to the MADEP within sixty (60) days after the scheduled sampling period. Finally, all results from the groundwater monitoring program will be compiled in the form of a table covering the current year and on a graph showing the historical trend. This information will be submitted to the MADEP annually (310 CMR 30.663 (9)). All groundwater observations shall include the date, the time and the depth to the groundwater water table.

3.1.4 Detection and Assessment Monitoring

Detection monitoring is required by the state and federal government to establish initial background levels and indicate the potential migration of contaminants. If a statistically significant increase over background levels is found for one or more of the constituents, an assessment monitoring program has to be established (USEPA, 1994). Figure 3-8 presents the flow path for required actions regarding detection and assessment monitoring based on Subtitle D, 40 CFR 258. To determine if a statistically significant change has occurred, the Student's t-test could be used or any of the tests specified in 310 CMR 30.663 (8).

If an assessment monitoring plan has to be implemented, the number of monitoring wells will be expanded according to the findings. In addition, the sampling frequency will be increased.

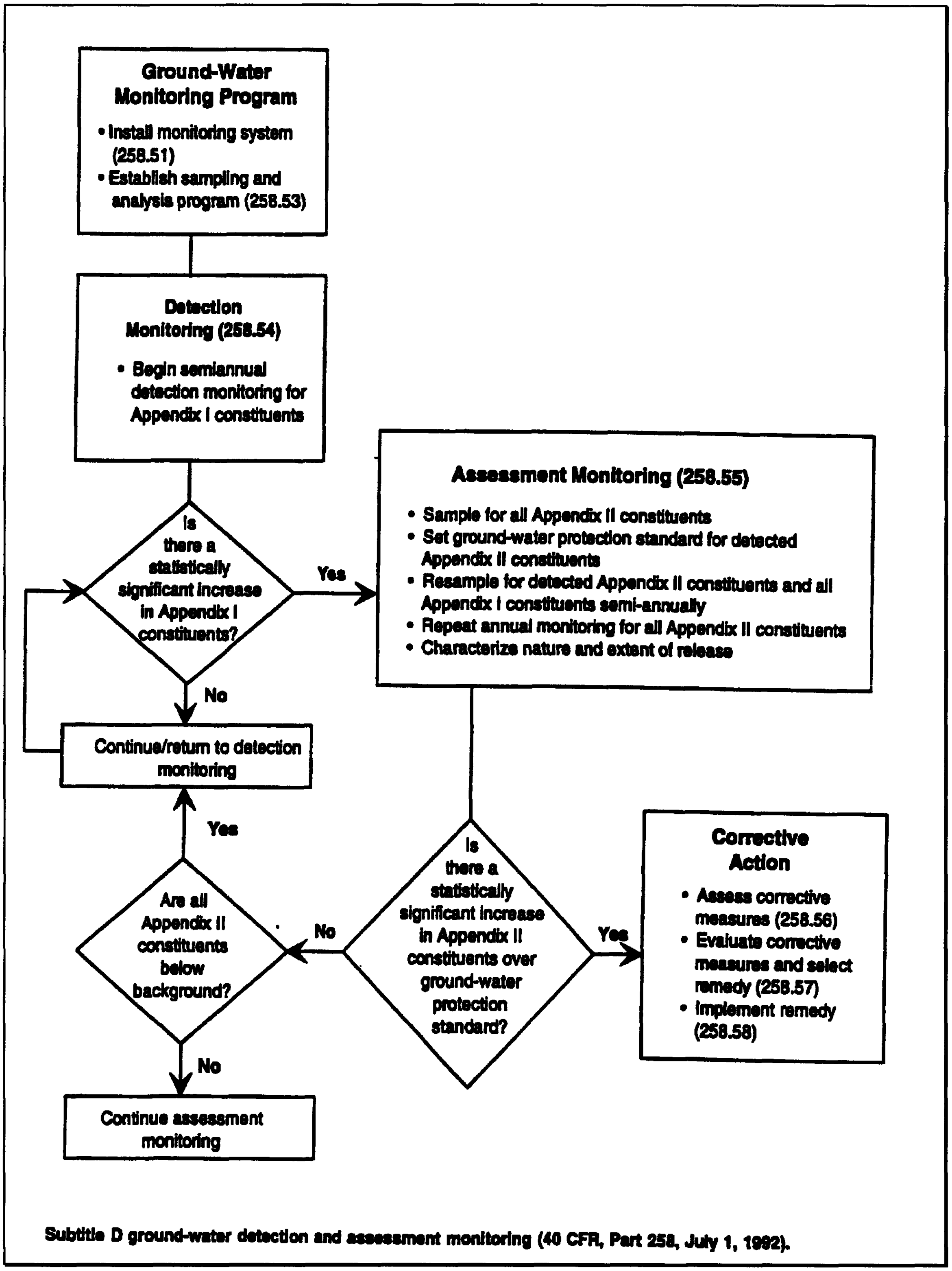


Figure 3-8 Flow Path For Required Actions Regarding Detection And Assessment Monitoring (USEPA, 1994b)

3.1.5 Monitoring Well Installation, Development and Surveying

Screen auger borings will be completed as monitoring wells in the 1951 cell area. The borings will be advanced using a slotted lead hollow-stem auger. Soil and groundwater sampling will be started at 5 feet below the water table and further samplings will be conducted at 5 foot intervals. The boring will be advanced until the bedrock is reached to allow for a complete vertical soil and contaminant concentration (Stone & Webster, 1996a). These samplings are expected to indicate that the 1951 cell is no longer a source of contamination, but nevertheless this fact should be investigated.

If the 1951 cell is capped along with the 1947 and 1957 cell (as has been suggested), an extension has to be designed to allow access to the monitoring well through the cover system. Details as to how to handle this occurrence will be developed at the time it is deemed necessary. Figure 3-9 shows a possible schematic representation of an extension through the cover system.

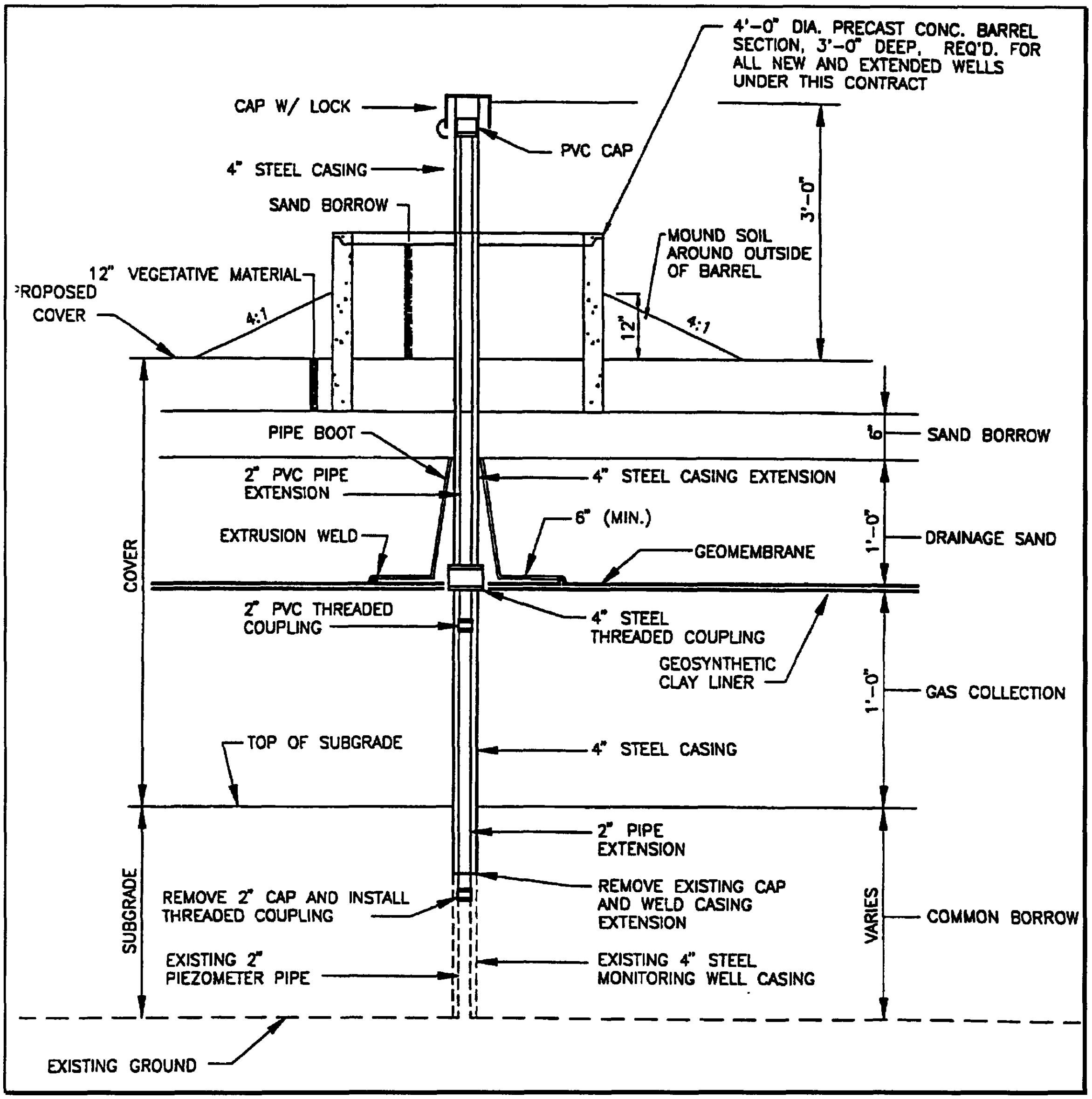


Figure 3-9 Possible Monitoring Well Extension (ABB Environmental Services, 1993b)

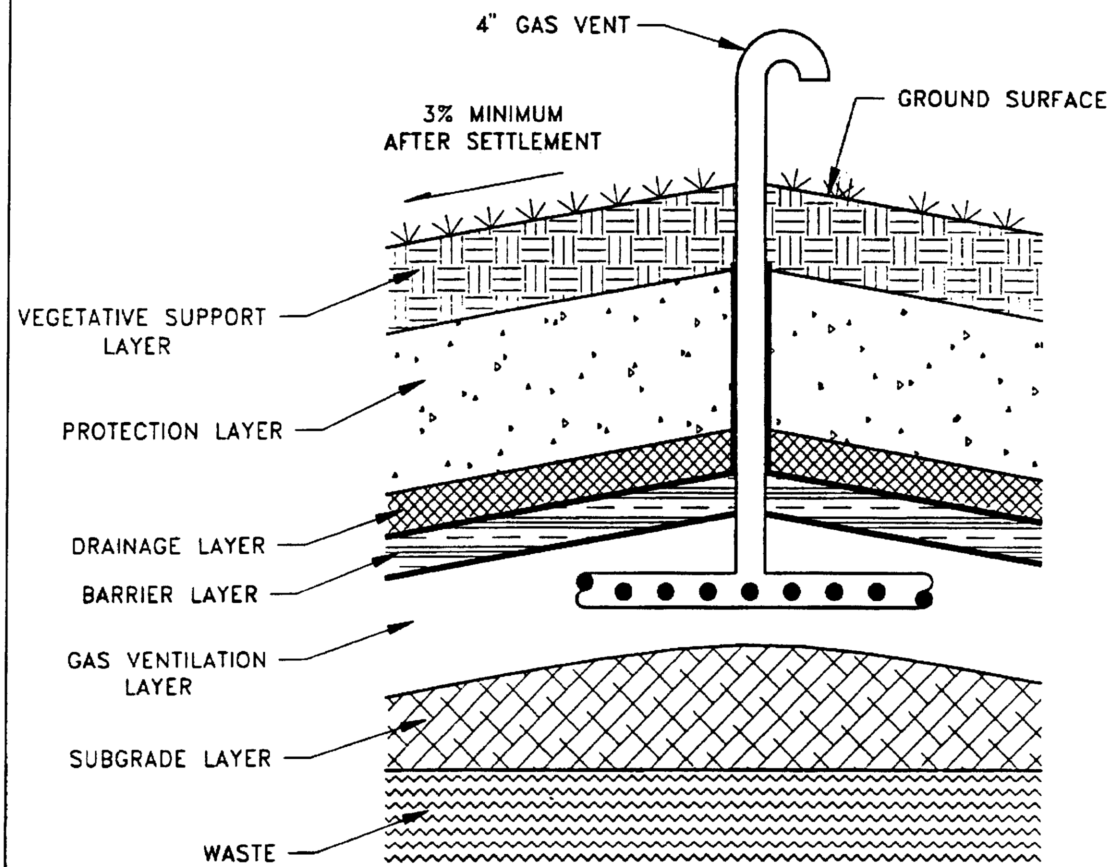
Monitoring wells will be developed by pumping and surging using an airlift method. Air lifting techniques will be used to lift an air-water column almost to the surface, then the air feed will be shut off and the column will be allowed to fall back into the well (Daniel, 1993). Repeated use of this technique can produce an effective surging action.

Following monitoring well installation and development, each well shall be surveyed vertically to provide ground surface elevation, groundwater elevation and the well riser elevation at each location. The well locations in the horizontal plane will be determined through an aerial survey.

3.2 Air Quality Monitoring

Typically, municipal waste facilities produce substantial amounts of gas due to the biodegradability of the waste. The 1951 cell is a mixed waste facility that contains both hazardous and municipal wastes, thus production of gas is expected to be limited. There are two reasons to suppose this. First of all, the cell has been in existence for 46 years and is composed mostly of burn-fill, suggesting that the majority of organic material has been oxidized by fire, thereby precluding further degradation by microbial action (Elias, 1996). In addition, soil gas surveys performed detected no significant amounts of VOCs in their soil vapor analyses (Stone & Webster, 1996b). Thus, a passive gas venting system was incorporated into the cover Elias designed. This system consisted of 10 gas vents. These vents release gases directly into the atmosphere.

Even though gas production is expected to be minimal, it is important for levels near the cover surface and around the cell perimeter to be monitored to ensure that standards are being met and that gas is not migrating offsite. Figure 3-10 presents a cross section of the cover design for the 1951 cell.



NOT TO SCALE

LAYER	MATERIAL	SPECIFICATIONS
Vegetative Support	Loam	6" thickness
Protection	Borrow Soil	18" thickness
Drainage	Geonet	Transmissivity > 3×10^{-5} m^2/sec
Barrier	Geomembrane over Geosynthetic Clay Liner	Geomembrane: 60mil VLDPE Geosynthetic Clay Liner: Gundseal with 40mil VLDPE Substrate
Gas Ventilation	Screened Borrow Soil	12" thickness Hydraulic conductivity > 1×10^{-3} cm/sec
Subgrade	Borrow Soil	2' minimum thickness

Figure 3-10 Cross-section of The Proposed Cover Design (Elias, 1996)

3.2.1 Number and Location Of Gas Probes

Currently, twelve (12) gas probes are installed in the LF-1 perimeter area. These probes were installed as part of the closure plans for the 1970, Post-1970 and Kettle Hole cells. Even though gas production is expected to be minimal, an additional gas probe is proposed for this monitoring plan since complete knowledge of the type of waste is unknown. Therefore its possible future behavior remains uncertain. This gas probe will be located across from the landfill cell along Herbert Road. Figure 3-11 shows the approximate location of the existing and additional probe. Regulations specify that for an area where there is no public access, the average spacing between probes shall be 650 feet. Thus, the monitoring probe is located approximately 650 feet from Gas Probe #12 and Gas Probe #1 (not shown in the figure). Figure 3-12 shows a schematic representation of the type of gas probe that will be employed.

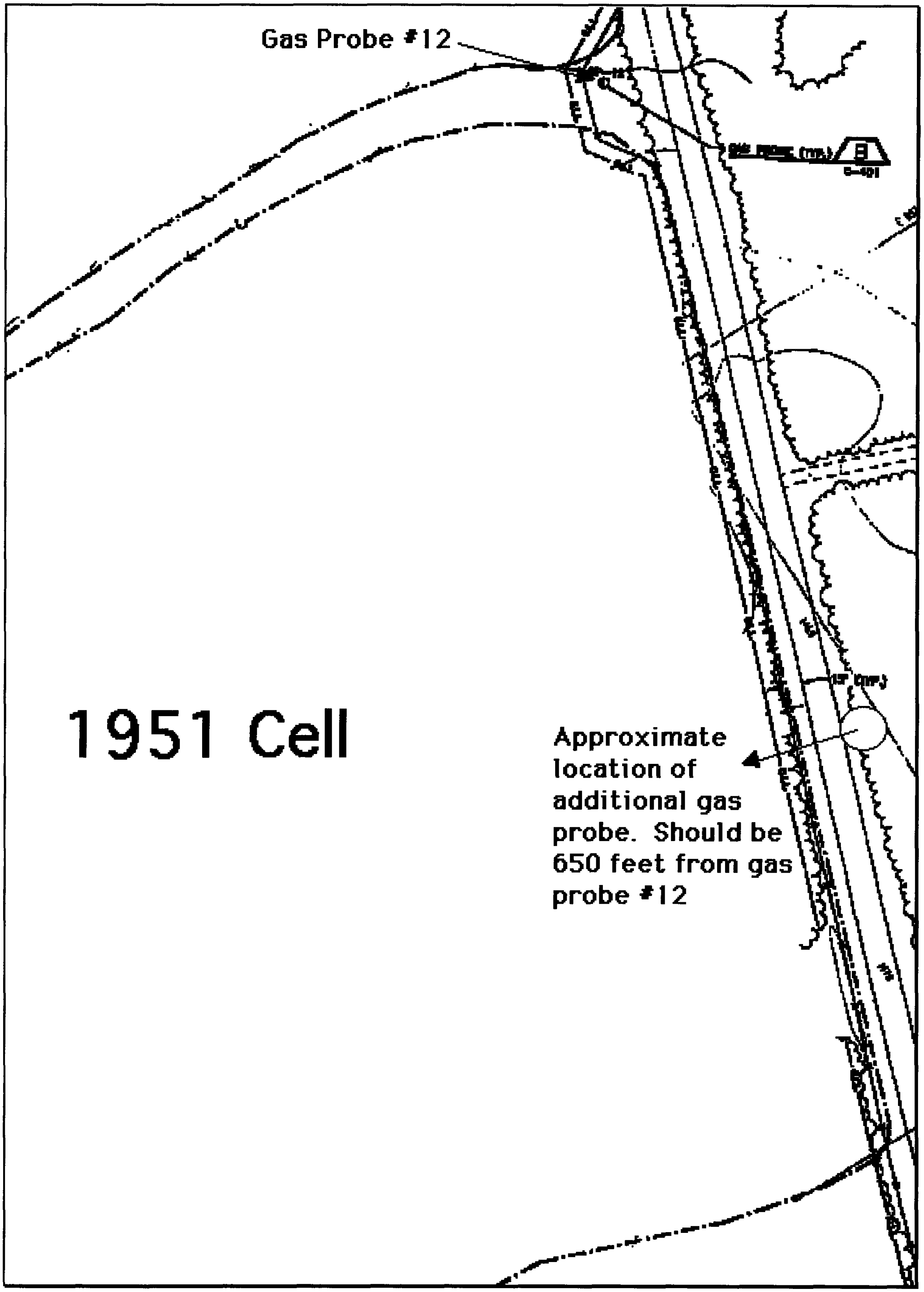


Figure 3-11 Location Of Additional Gas Probe (ABB Environmental Services, 1993b)

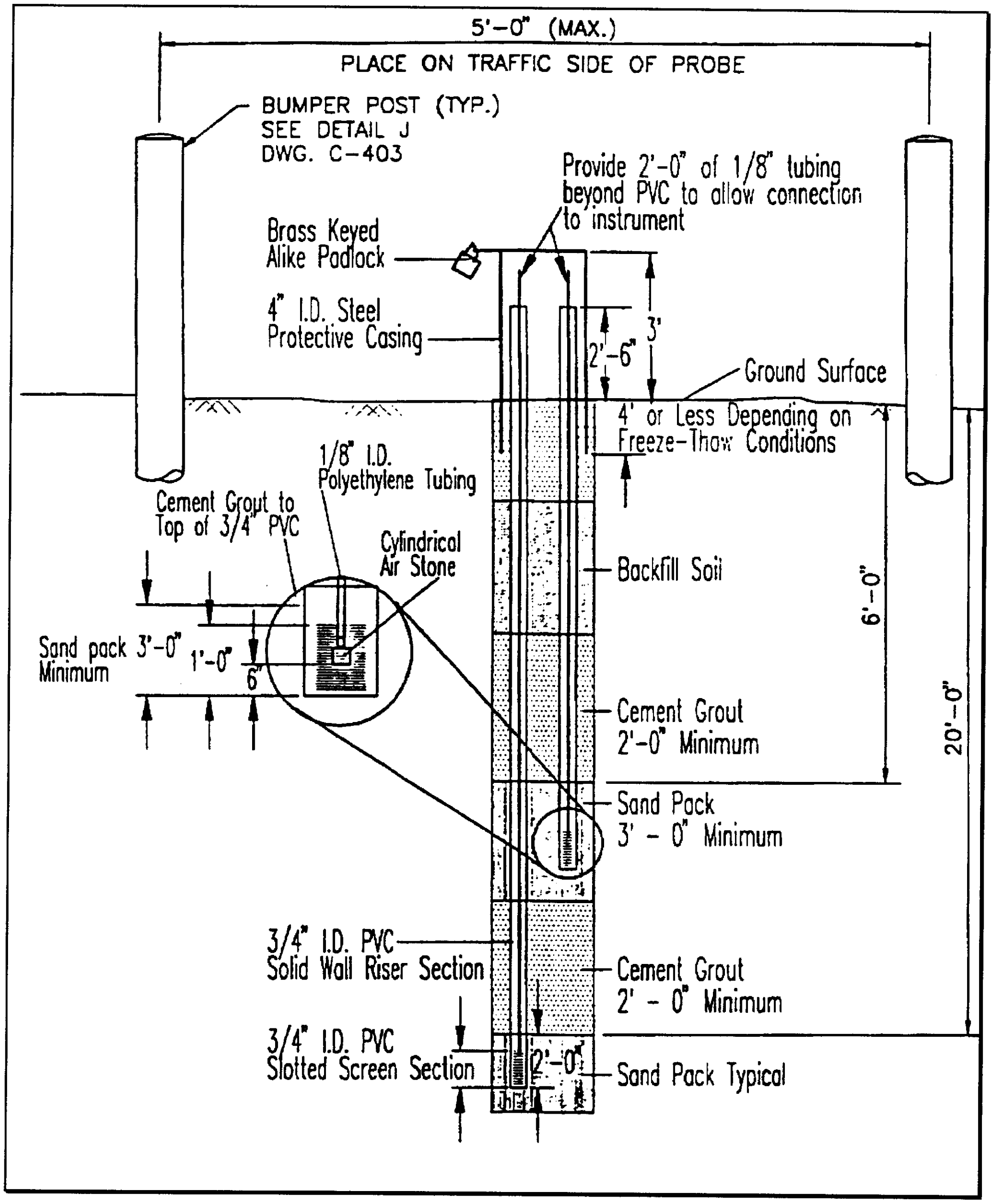


Figure 3-12 Shows A Schematic Representation Of A Gas Probe (ABB Environmental Services, 1993b)

3.2.2 Monitoring Frequency and Required Analyses

Gas monitoring will occur in each quarter. Table 3-2 presents the parameters to be monitored using the gas probes. The concentration of gases shall be no greater than 25% of the Lower Explosive Limit (LEL).

Table 3-2 Air Quality Monitored Parameters

Air Quality Monitored Parameters
Methane
Explosive Gases
Volatile Organic Compounds
Hydrogen Sulfide

The MADEP suggests the following sampling procedures for gas probes (MADEP, 1993). Samples shall be collected prior to purging to simulate gas build up in a closed space (worst case scenario). Then the gas probes should be purged of two bore volumes and the sample collected and/or measured again. Purging can be accomplished by the use of an aspirator or a portable vacuum pump. The samples shall be analyzed via the connection of field analytical equipment directly to the sample port on the soil gas probe. A water trap may be necessary to protect instrumentation depending on the moisture content of the landfill gas and sensitivity of the field equipment. Instruments that can be used in the field include photo ionization meters, explosimeter, organic vapor analyzer and a multi-gas meter.

To properly characterize the landfill gas, samples shall also be taken from the passive gas vents. Samples will be evaluated by using both field techniques and laboratory analyses. Techniques for collecting laboratory samples from gas vents are using a collection media, grab samples in evacuated vessels or active pump and filter samples.

All QA/QC methods should be followed to ensure accurate analyses of the field samples. Finally, an annual report must be presented to the DEP that gives data generated during the quarterly or semi-annual sampling events. This should be accompanied by a discussion in detail of the contaminant profile, historical trends or unusual events associated with the data and the interrelationship between the sampling arising from the various media in the monitoring program.

3.3 Surface Water Monitoring

Surface water runoff shall be monitored to determine if any contamination is present. This monitoring is helpful in indicating if there is contamination and where it might be originating from. The cover design includes a perimeter drainage system as well as a toe drain that collects water from the drainage layer. The perimeter drainage system is diverted to the culvert between the Kettle Hole and the Post-1970 Cell, which then discharges into the borrow-pit recharge area (Elias, 1996). Surface water samples shall be collected at the diversion point since sampling in the borrow-pit area would make it impossible to determine which cell is contributing to possible contamination. The toe drain is designed to discharge in the southeast corner of the cell. From there, the flow is to be transported via culvert to the borrow-pit area (Elias, 1996). For the same reason stated before, samples shall be taken at the point of diversion.

Satisfying 310 CMR 19.132, the same parameters that are analyzed for in groundwater shall be analyzed for in surface water. Please refer to section 3.1.3 of this report for these parameters. Determination of an adequate site for collecting background surface water data will be done at the time that the monitoring program is activated.

3.4 Maintenance Activities

The landfill component system shall be operated and maintained throughout the post-closure period, as required in order to ensure the proper functioning of the landfill system and to protect public health, safety and the environment (GZA, 1995). Maintenance activities shall be conducted, (i) according to the schedule indicated in this plan (section 3.4.1), (ii) based on the results of inspection, (iii) based on whenever a deficiency which impairs the functioning and integrity of the landfill system is detected. The cover design for the 1951 cell is presented in Figure 3-10 of section 3.2.

This part of the plan will include a description of all activities necessary to maintain the integrity of the cover and vegetation, gas ventilation system, groundwater monitoring systems and security devices.

3.4.1 Facility inspections

Routine inspections are needed to characterize the condition of landfill closure facilities. Table 3-3 presents a listing of items to be inspected, as well as the frequency of inspection. In the following sections, a detailed maintenance plan will be presented for each of these items. These inspections will be performed by MMR personnel following the same route in each walkover. Figure 3-13 shows a map of the walkover that the inspector shall follow every time the inspection of the final cover system is performed. By following the same route, the inspector will be able to notice subtle changes to the system that would otherwise go undetected. Gas vents risers have been used as benchmarks in determining the route. The cell is relatively flat, with a slope for the cover system of 3%. Oblique aerial photographs should be taken once a year to provide a different perspective in assessing the integrity of the cover (Lutton, 1987).

Table 3-3 Inspection Frequency

Inspection Item	Frequency of Inspection
Final Cover	Monthly site walkovers for first quarter, two walkovers during second quarter and quarterly walkovers for the remainder of the first year. For the next 29 years, semiannual inspections.
Vegetative Cover	Same schedule as final cover.
Drainage System	Same schedule as final cover.
Groundwater Monitoring System	Semiannually.
Surveyed Benchmarks	Semiannually.
Gas Venting System	Quarterly.
Security Systems	Semiannually.

Inspection findings will be recorded on a post-closure inspection log form. These inspection logs should include:

- name of the person(s) performing the inspection.
- date, time and prevailing weather conditions.
- a description of the inspection methods used (visual or mechanical).

- results of inspection.
- recommendations for repair,reconstruction and/or replacement of damaged facilities.

An inspection log form was developed and is presented in Appendix A.

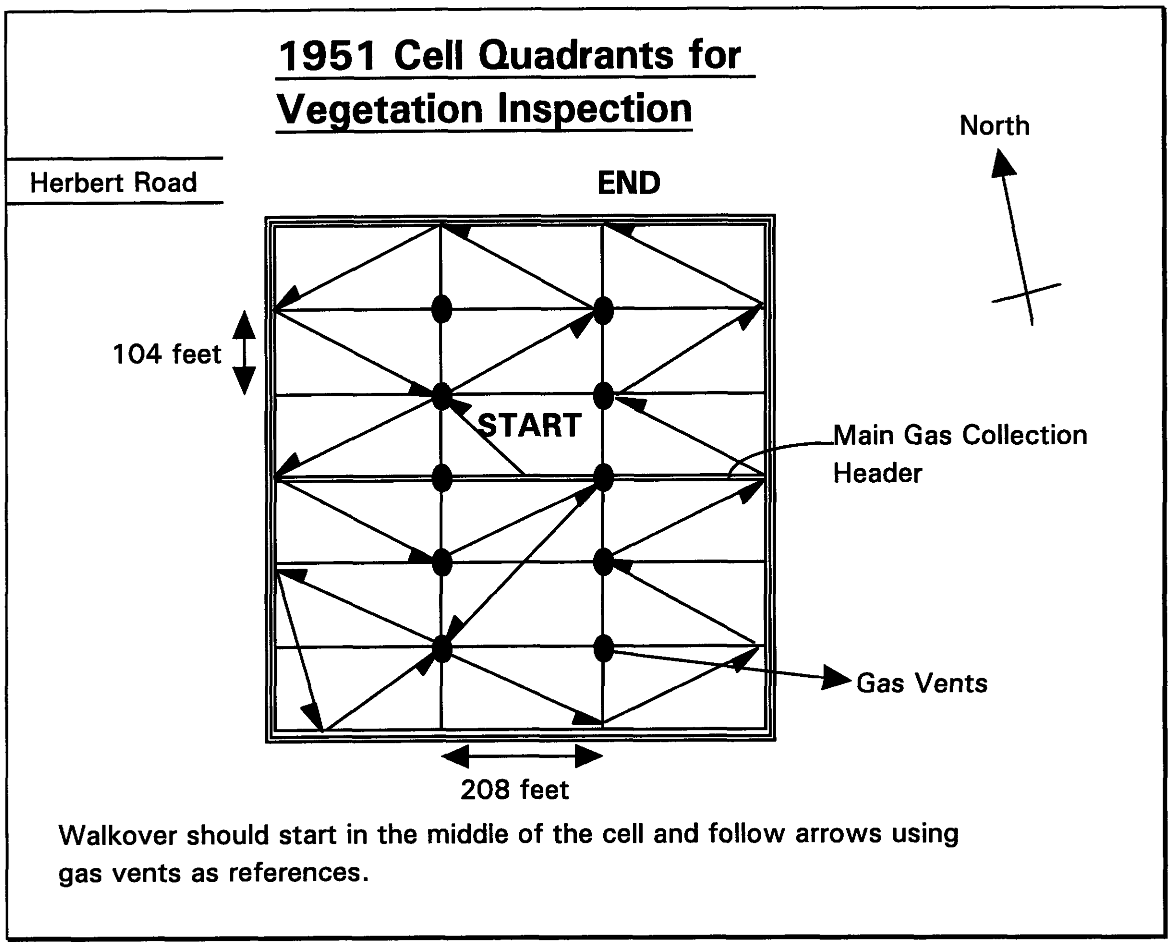


Figure 3-13 Walkover Map for the 1951 Cell

Should experience indicate that that landfill conditions are stable, with little change between inspections, the inspection frequency might be reduced. Any desired modifications to the inspection plan have to be submitted to the MADEP before any changes actually take place.

3.4.2 Maintenance of Cover and Vegetation

All of the maintenance operations presented below are directed to maintain the integrity of the cover system. The vegetation provides the primary protection for the sand cover, and it must be maintained for it to be an effective barrier against erosion and infiltration (General Research, 1981). Refer to Figure 3-10 for a description of the different components of the cover system.

3.4.2.1 Cover Maintenance

Cover maintenance includes activities needed to repair damages to the cover caused by routine weather conditions as well as periodic natural events such as storms, droughts, frosts, erosion, seismic activity or subsidence. Section 3.4.1 specifies the frequency of inspection for the cover system. Table 3-4 presents possible problems with the cover system and recommended repairs.

Table 3-4 Cover Design Problems and Concerns (USEPA, 1988)

Problem	Repairs and Concerns
Gully Development	-Backfill to original grade with stone of narrow size range -Regrade cover -Replant vegetation
Subsidence	-Backfill with additional cover soil (care should be taken to maintain continuity of low permeable soil layer, geomembrane and drainage layer).
Slope Instability	-Reconstruct cover -Flatten slopes -Add toe berm along base of slope
Erosion	-Affects drainage systems, see section 3.4.3
Seismic Activity	-Inspection should be done after a major seismic activity and repairs are dependent on type of problem
Geomembrane	-Erosion or burrowing animal may result in damage -If problems arise, the geomembrane should be exposed and repaired; seals shall also be checked and repaired.

3.4.2.2 Vegetative Cover

The surface layer in the closure design for the 1951 cell is comprised of warm season grass mix. This choice of vegetation allows for possible future recreational use of the land, is aesthetically pleasing, promotes evapotranspiration, decreases erosion and decreases water run-off velocities (Elias, 1996). Short-term monitoring of this vegetative cover is very important to insure the cover system's proper function. Patterns of germination and early plant growth need to be documented and bare spots examined to identify factors that impede the establishment of vegetation (Caldwell,1993).

The 1951 cell is approximately 626 feet (191 meters) to a side and has roughly a square shape, as determined by magnetometer and ground-penetrating radar surveys (Stone & Webster, 1996a). To properly monitor the vegetative growth, the cell will be divided into 18 quadrants of approximately 104 ft x 208 ft (32 m x 64 m). These quadrants are defined by the gas vents present in the system. Figure 3-14 shows a plan view of these cell quadrants as well as the location of the gas vent risers. For each of these quadrants, the following parameters will be monitored:

- Number of plants: measured using the defined quadrants.
- Root penetration depth: excavation method used specifically for each plant species present.
- Plant height and vigor: to assess proper plant conditions and growth.
- Percent groundcover: to determine if proper growth of plants is occurring.

As a corrective measure, eroded or bare areas shall be refilled with vegetative support material and reseeded as required. In addition, trees or woody vegetation with deep root systems potentially detrimental to the landfill cap shall not be permitted to become established.

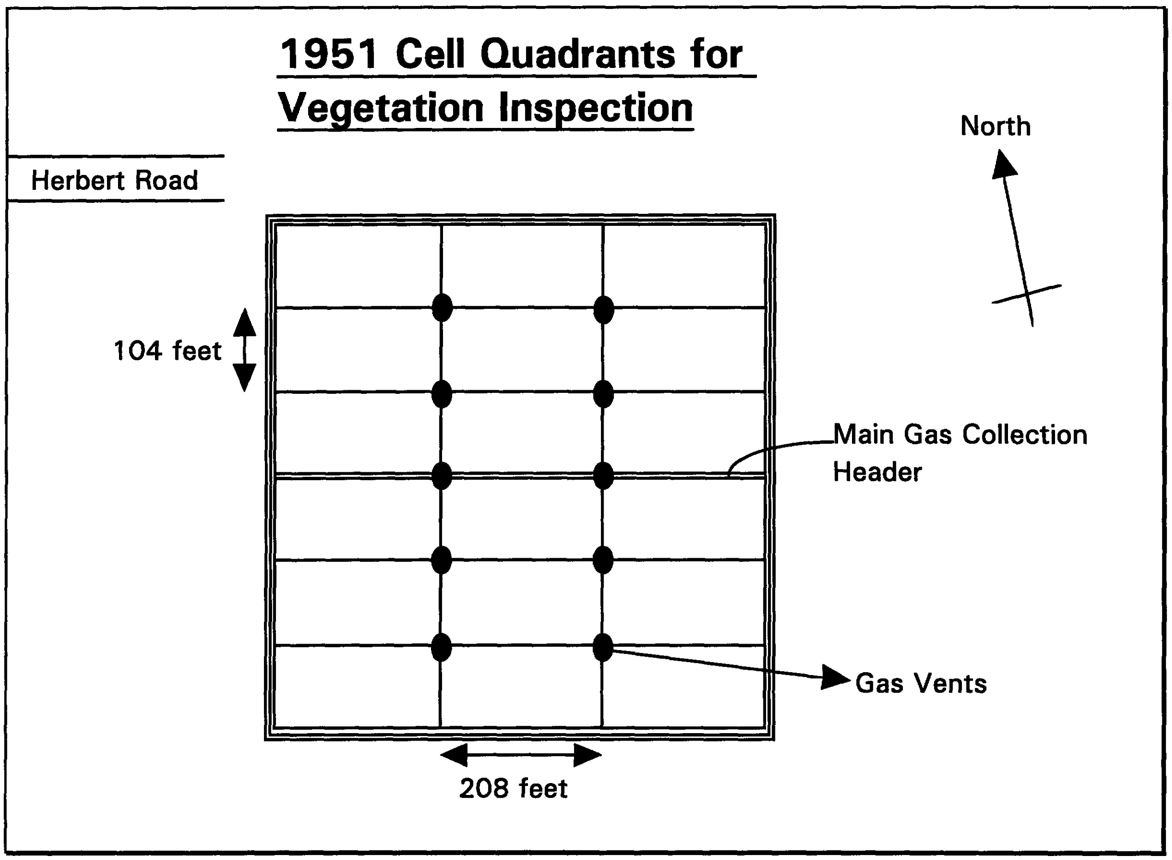


Figure 3-14 Cell Quadrants for Vegetative Cover Inspection

3.4.2.3 Soil

The proper maintenance of the soil requires the monitoring of the following parameters:

- soil loss.
- soil chemistry.
- physical soil parameters.

Soil loss will be determined by measuring the quantity of soil accumulated in the run-off collection system. In addition, any gullies that develop should be measured with respect to width, depth and length in order to estimate the amount of soil lost (Caldwell, 1993). First year soil loss is estimated to be 2.3 tons/acre-yr (Elias, 1996), with a suggested rate of 2.0 tons/acre-yr by the USEPA. Soil loss during the first months will be the greatest, therefore special care has to be taken in this period to ensure that the loss is kept to a minimum and any perceived problems remedied immediately. For this reason, inspections in the first year will occur with more frequency. Afterward, the cover was designed for a soil loss of 0.5 tons/acre-yr (Elias, 1996) with 80% cover grass, which suggests that soil loss should not be a big problem in subsequent years.

Soil samples should be taken at the time of inspection and analyzed for their chemistry and physical parameters. These analyses are important to prevent unwanted soil conditions that may compromise the vegetative cover. Soil samples should be analyzed for pH, nutrient content, moisture content, cation exchange capacity and organic matter content (Caldwell, 1993).

3.4.2.4 Mowing, Fertilizing, Sprinkling, Reseeding And Mulching Schedule

Once the vegetative cover is well established, the focus of the cover system maintenance program shifts to periodic mowing, reseeding and mulching of bald spots and eroded areas. Application of fertilizer will dominate in the early years. For the first three (3) years, fertilizing should occur annually. To ensure that the warm season grassy mix grows accordingly, soil tests for pH, Mg, Ca, P, NO_3, NH_4, K, CU, Fe, Zn, Mn, conductivity , particle size distribution, density and organic content need to be performed to determine the proper fertilizer for the soil conditions. In general, a fertilizer of type 10-10-10 (nitrogen, phosphate, potassium percentage, respectively) grade is used and applied with a grass drill method as recommended by the Soil Conservation Service (SCS) (Elias, 1996).

Mowing promotes the establishment of a dense sod and should occur once a year and be performed by personnel of the MMR. Reseeding and mulching should occur whenever it is required by the soil and vegetative cover monitoring program to maintain a vigorous vegetative cover. Seeding mixtures shall be selected according to recommendations from the SCS. For mulching, hay or straw are the most commonly used materials for newly seeded areas. Mulching helps to hold moisture in the soil, protect the soil from erosion, hold the seed in place and maintain relatively constant soil temperature. The mulch should be placed as soon as possible after seeding is complete and not later than 48 hours after seeding (Elias, 1996).

3.4.2.5 Rodent And Insect Control Program

A rodent and insect control program is necessary to ensure the integrity of the cover system. Following the schedule of cover inspection, the soil will be checked for the presence of mammal and reptile burrows. If burrows are located, they should be filled with a quick-setting foam, excavated and the depth of the burrow recorded. Any ant tunnels should also be excavated and the amount of soil removed should be recorded.

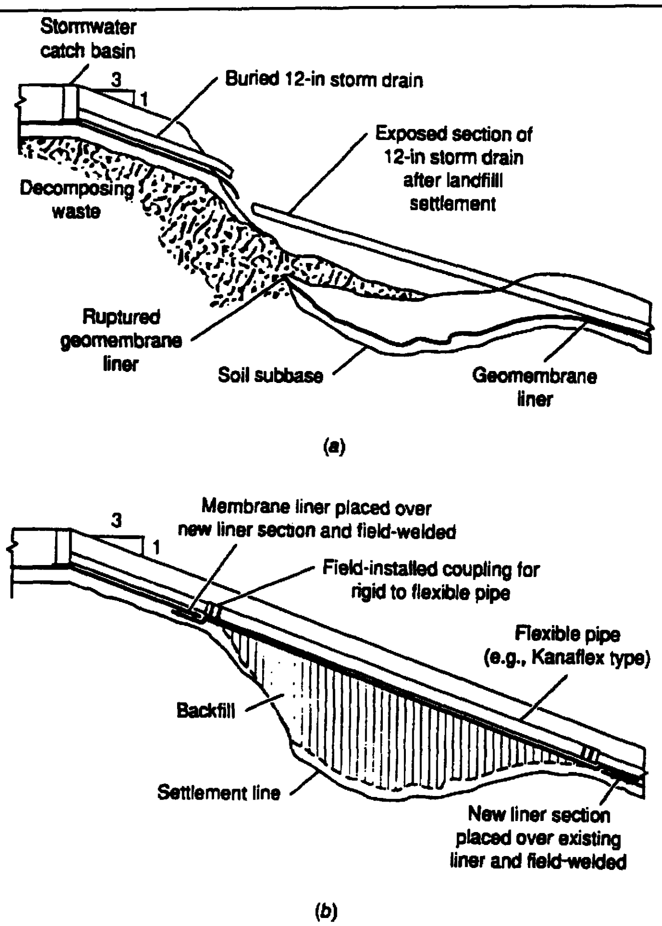
3.4.2.6 Freeze/Thaw Effects

Freezing and thawing could compromise the integrity of the cover system. Freezing of the geosynthetics could result in brittle failure and thawing could produce a saturated soil condition which could cause instability problems. Frost depth in the area of Massachusetts is between 27 and 30 inches (USEPA, 1991). Freeze/thaw effects are expected to be minimal due to the design of the cover system. A geosynthetic clay liner (GCL) was chosen over a compacted clay liner (CCL) due to its superior performance in freeze/thaw testing. Tests performed on four commercially available GCLs demonstrate that their tolerance to frost effects are higher than CCLs. The designed GCL is Gundseal with 40 mil Very Low Density Polyethylene (VLDPE) substrate. In addition, the use of a VLDPE geomembrane layer of 60 mil provides further protection for freeze/thaw effects. Nevertheless, long term performance and durability of geosynthetics is still uncertain and thus should be monitored. This monitoring should be performed at the time of cover inspection by noting the conditions of any exposed geosynthetic material and should help in the study of geomembrane durability. Geomembrane durability is investigated in Chapter 5.

3.4.3 Drainage System Control

The drainage control systems includes the perimeter drainage and a drainage layer. Both of these are subject to long term settlement and clogging by erosion and siltation. Maintenance is important because these channels direct surface water runoff away from the disposal area where it would infiltrate the soil and promote leaching (General Research, 1981). The 1951 cell includes a 12 inch drainage sand layer with drainage pipes that discharge into diversion trenches surrounding the cell. Inspection frequency is specified in section 3.4.1.

Problems that may arise with drainage systems are the erosion of the sand layer, the obstruction of flow, biological clogging (plant roots, burrows), broken drainage pipes and insufficient drainage due to loss of slope. The cover design contains hay bale erosion control that shall be monitored in accordance with the schedule to reduce possible erosion problems. The establishment and maintenance of a vigorous vegetative cover will serve as the primary erosion and sediment control. If any sand is present in the ditches or drainage pipes, it should be removed and collected to estimate soil loss. Figure 3-15 shows a schematic representation of the repair of a broken drainage pipe. Finally, if grades are affected, immediate actions should be taken to correct this problem. Actions include changing the grade of the drain or ditch and resurfacing the cover.



Schematic representation of the repair of a broken drainage pipe after landfill settlement: (a) damaged drainage pipe and (b) repair of broken section of drainage pipe.

Figure 3-15 Schematic Representation Of The Repair Of A Broken Drainage Pipe (Tchobanoglous, 1993)

3.4.4 Settlement, Subsidence and Displacement Control

Cover system performance may be compromised if the cover settlement exceeds its design value. Settlement at the center of the cover is expected to be 2 feet, and at the edge of the cover 1 feet. Thus, differential settlement is expected to be approximately 1 foot. Since the nature of buried waste is unknown, substantial settlement monitoring is suggested. Therefore, settlement monitoring through surveys at cross sections should occur annually for the 30 years of the required post-closure management. Settlement platforms were incorporated in the final cover design to facilitate the assessment of possible settlement. Also, localized settlement should be monitored since the possibility of a collapsed metal drum occurring due to corrosion or compression may be high.

Major subsidence depressions must be remediated below the level of the barrier system to avoid long-term acceleration of the subsidence due to a "roof-ponding" mechanism (USEPA, 1991). Section 3.4.7 will present repair methods for such a problem. In general, low areas or depressions that develop shall be refilled (and reseeded) to maintain positive drainage. Additional cover material shall be placed and graded as needed to maintain minimum slopes consistent with the surrounding areas.

3.4.5 Maintenance of Groundwater Monitoring System

The groundwater monitoring system will be inspected semiannually, at opposite quarters from the sampling session. This is to ensure that when the sampling period is reached, monitoring wells are working properly. Maintenance of the monitoring wells will include inspection of the well itself, protective casings, seals and caps, pumps and general equipment. Problems that may arise are tempering, rust, cracking, pitting, flaking, tampering and degradation of pipe. They shall be kept in a serviceable condition and be kept locked when not in use.

If repairs are needed, MMR personnel should contact the contractor to perform the necessary repairs. Should a well become unserviceable beyond repair, the well shall be abandoned in place by filling with bentonite cement grout. The impact of such a closure to the groundwater monitoring program shall be evaluated at the time and necessary modifications to the program shall be made. This plan could be modified after MMR personnel acquire more experience with the monitoring system.

3.4.6 Maintenance Of Gas Collection Monitoring System

Gas probes should be inspected at the time of sampling. Gas vents and gas probes should be inspected and irregularities should be recorded and presented to the contractor that installed them. Irregularities of gas vents could occur due to damage from mowing or vandalism. A damaged vent pipe can allow surface water to enter the gas venting system and bypass the cover (USEPA, 1994). Inspection of bumper posts for the gas probes across Herbert Road, and any replacement to these, should be performed by MMR personnel following design drawings. Gas probe equipment shall be maintained per equipment manufacturers recommendations.

When appropriate, and based on monitoring results, certain portions of the gas monitoring system, such as probes with low or no methane content, may be shut off.

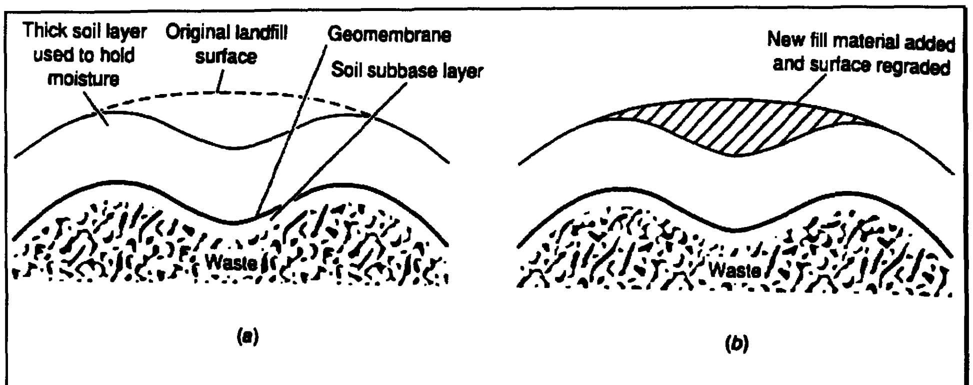
3.4.7 Planned Responses To Probable Occurrences

Regulations require any post-closure management plan to take corrective actions to remediate and/or mitigate conditions that would compromise the integrity of the final cover. Preventative and corrective or unscheduled maintenance will be performed on the following:

- Final cover.
- Repair of security control devices.
- Erosion damage repair.
- Settlement, subsidence and displacement.
- Run-on and runoff control structures.
- Gas collection/venting system.
- Groundwater and gas monitoring wells.

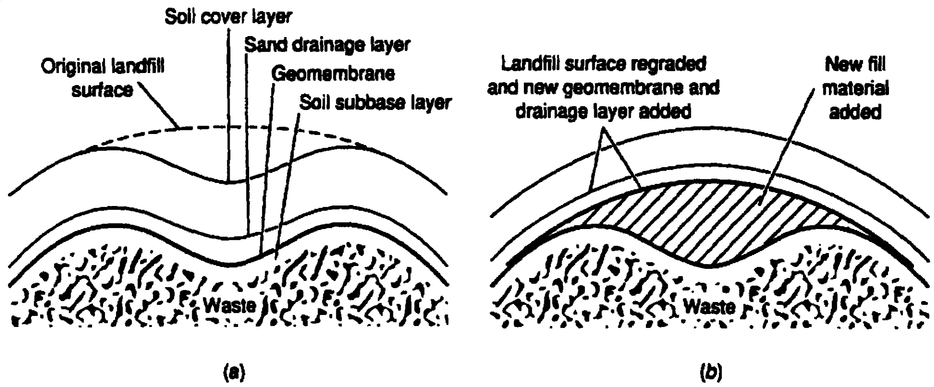
For examples of possible repairs of common final cover problems refer to Table 3-4 in section 3.4.2.1. Drainage system repairs are presented in section 3.4.3.

Loss of cover integrity could be repaired according to the actions described in the Figures 3-16 - 3-18.



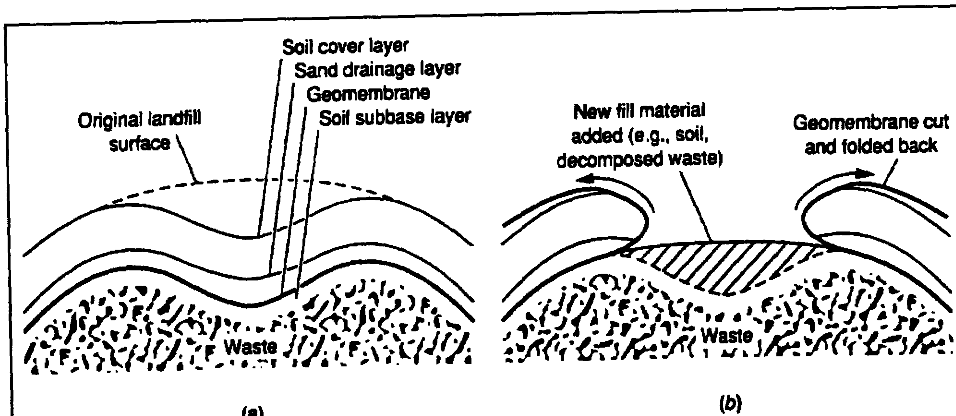
Schematic representation of a repair made for the purpose of restoring drainage over a landfill cover employing a thick soil cover and a geomembrane: (*a*) landfill after closure and settlement and (*b*) landfill after repair to restore surface drainage.

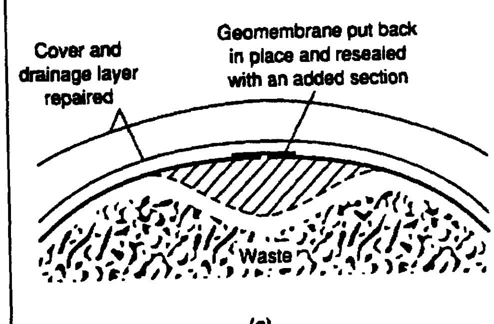
Figure 3-16 Possible Corrective Measures (Tchobanoglous, 1993)



Schematic representation of the replacement of landfill cover after settlement involving the regrading of the landfill surface and the installation of a new geomembrane, drainage layer, and soil cover: (*a*) landfill after closure and settlement and (*b*) new landfill cover installed after settlement.

Figure 3-17 Possible Corrective Measures (Tchobanoglous, 1993)





Schematic representation of a repair made for the purpose of restoring drainage over a landfill cover employing a geomembrane: (a) landfill after closure and settlement, (*b*) landfill repair procedure, and (*c*) landfill after repair to restore surface drainage.

Figure 3-18 Possible Corrective Measures (Tchobanoglous, 1993)

3.4.8 Security

A perimeter fence has been completed along the roads surrounding the landfill area to deter any vandalism or outside interference that could jeopardize the proper functioning of the cover system. The fence is a galvanized chain-link steel fence with double swing gates and locks. Since outside interaction inside the Otis Air Force Base is minimal, semiannual maintenance and inspection should suffice. The usual problems associated with security devices are presented in Table 3-5.

Table 3-5 Security Maintenance Problems and Concerns

Item	Problems and Concerns
Facility Gates	Corrosion, damage to chain-link fence and broken locks
Locks	Tampering and rust
Facility Fences	Corrosion, damage to chain-link fence
Warning Signs	Missing or damaged

In addition, surveyed benchmarks should be protected and maintained. Finally, access roads are to be maintained in satisfaction of the post-closure management plan for the 1970, Post-1970 and Kettle Hole.

3.5 Facility Records And Submittal Of Reports

The on-site office should keep records of the following items:

- This Closure/Post-Closure Plan and any modifications.
- As-built documentation and design plans for the final cover construction.
- Final Cover Design plans.
- Historic Monitoring data.

- Pertinent regulatory permits and approvals.
- Post-closure inspection record, biennial reports and post-closure cost estimates.
- Other records pertinent to post-closure administration, maintenance, monitoring and inspections.

Reports shall be compiled and presented to the MADEP with the following:

- Ground and surface water monitoring reports shall be submitted to the DEP within 60 days after the sampling events.
- A biennial report, describing activity at the site and summarizing the results of environmental monitoring, periodic inspections and other pertinent information will be submitted to the DEP in accordance with the requirement of 310 CMR 19.142 (6).
- An annual report on the performance and maintenance of the landfill gas recovery system in accordance with the requirement of 310 CMR 19.121 (4)(d).
- Site Manager shall notify the DEP at any time should conditions develop which constitute a threat to public health or safety or the environment.

4. POST-CLOSURE LAND USE

Recently, closed landfill sites are increasingly being considered as potential areas for development. Projects range from parks to commercial developments. Although, the utilization of landfills may be favorable, such utilization must take into consideration the unique problems encountered in construction on old landfill sites (MADEP, 1993). The possibility of developing the landfill site at the MMR could offer an interesting alternative for the residents of the area. In this chapter, the topic of post-closure land use will be discussed. First, an overview of the factors that should be considered for the effective design of a post-closure land use plan will be presented. This will be followed by some alternatives available for land use. Then, the criteria specified by the state of Massachusetts regarding post-closure land use will be given. Finally, an assessment as to possible future land use for the 1951 cell will be presented.

4.1 Factors to Consider

Careful consideration and evaluation of the following factors are necessary if the development of an old landfill is to be successful. The factors to be discussed are: landfill closure and waste characteristics, settlement, civil infrastructure constraints and land use alternatives.

4.1.1 Landfill Closure And Waste Characteristics

For an effective development of an old landfill, the cover system design should take into consideration and include the following aspects (Dunn, 1995):

- A high level of detailed site evaluation.
- Specific information regarding waste characteristics.
- The incorporation of redundant project features.
- Careful construction with a higher than normal level of construction quality assurance.
- Careful planning and implementation of inspections and maintenance, as well as potential response actions should problems occur.

In addition, the closure design must consider (Dunn, 1995):

- Site closure and maintenance of waste containment.
- Control of landfill gas and leachate.
- Limitations of site infrastructure.
- Health and safety issues during the site investigation phases, site construction and site use or occupancy.

4.1.2 Settlement

The magnitude of expected differential and total settlement will affect the type of structure that can be built on an old landfill site. Several factors affect the magnitude of settlement, including: the composition of refuse, refuse density, refuse layer thickness, overburden weight, amount of moisture and oxygen that reach the waste and the temperature within the waste layer (Elias, 1996). The three basic mechanisms of settlement in a landfill are: mechanical compression, raveling and decomposition. Determining the magnitude and rate of settlement is a very important factor for aiding in the selection of an appropriate land use application.

4.1.3 Civil Infrastructure Constraints

The design of foundations at landfills requires careful and detailed analysis, because failure to properly consider the many factors associated with foundation over, or through, the wastes can result in poor foundation performance (Dunn, 1995a). There are two types of foundations that can be built in landfills, namely shallow foundations or deep foundations.

Shallow foundations generally support lightly loaded structures, such as wood frame constructions of two or three stories in height (Dunn, 1995a). There are three different types of shallow foundations: conventional spread footings, reinforced concrete mats and grid foundations consisting of column footings tied together with a system of grade beams and usually an integral concrete floor. These three configurations are presented in Figure 4-1. With the use of shallow foundations, conventional bearing capacity analyses are utilized for the design. Usually, a layer of engineering fill sufficiently thick is used to provide the necessary soil bearing capacity (Dunn, 1995a). The construction of shallow foundations usually does not encounter the underlying waste and therefore follows conventional design and construction practices (Dunn, 1995a).

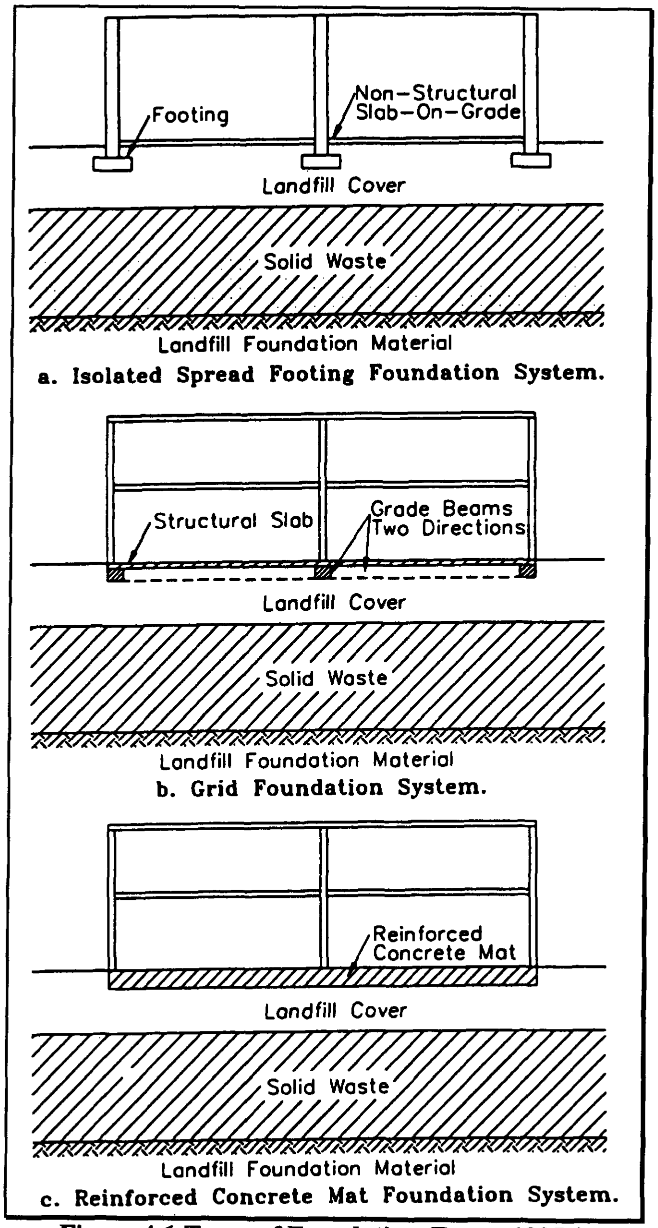


Figure 4-1 Types of Foundation (Dunn, 1995a)

The type of deep foundations generally utilized are driven piles. The pile types commonly used are pre-cast pre-stressed concrete piles, steel H-piles or steel pipe piles (Dunn, 1995a). The design of pile foundations must include the analysis of the following categories: pile capacity (vertical and lateral), downdrag loads due to settlement, constructability and construction impact on the landfill environment, corrosion resistance of pile, and the environmental protection and maintenance of the integrity of containment (Dunn, 1995a). Problems associated with the construction of deep foundations are: penetration of waste, disposal of displaced waste, downdrag (negative skin friction) and other common geotechnical challenges (Dunn, 1995a).

4.1.4 Land Use Alternatives

The alternatives for post-closure land use include (depending on the site):

- Recreational uses (passive and active): sports, park facilities, community centers and open spaces.
- Commercial Developments: retail stores, warehouses, office buildings, manufacturing facilities and schools.
- Residential: single family homes, townhouses and apartments.
- Closure and Remediation Facilities: maintenance buildings, groundwater or leachate treatment plants and landfill gas treatment plants or flares.

4.2 Criteria for Post-Closure Use

The Department of Environmental Protection of the state of Massachusetts specifies that the post-closure design plans must ensure that the proposed use of the site will protect public health, safety and the environment. The criteria to be addressed include (MADEP, 1993):

- Integrity of the final cover must not be impaired by the proposed use. Design features such as additional cover material may be required to ensure protection of the low permeability barrier layer.
- The landfill must be adequately maintained including: erosion control, leachate management and mowing of vegetation.
- The final cap, leachate collection system, drainage systems, gas vents or gas collection wells and monitoring program or other features of the landfill designed to protect public health, safety or the environment cannot be adversely affected by the proposed use.
- Gas control technology must be employed where necessary.
- Design and maintenance of the proposed use must address landfill settlement.

4.3 Alternatives For The 1951 Cell

Alternatives for the development of the cover system designed for the 1951 cell are limited. First of all, the presence of unknown waste and live ordnance in the cell eliminates the possibility of using a deep foundation system to support any structure. A shallow foundation might be incorporated in the cover system, since, if correctly designed and constructed, such a system would not come in contact with the buried waste. However, this alternative may be cost prohibitive since alteration to the current cover system would have to be performed; this alteration being necessary since the cover system was not designed to support a shallow foundation system.

In addition, if any development occurs, the post-closure management plan presented in Chapter 3 would have to be amended and corrected to satisfy the additional requirements stipulated by the MADEP. Also, the fact that the landfill does not contain a leachate collection system may deem it an unsuitable site for post-closure land development in the eyes of the MADEP. Finally, the public may not accept the development of land on top of a hazardous waste landfill and therefore, increased liability concerns for the developer might arise.

Therefore, the best alternative for post-closure land use of the 1951 cell is passive recreational areas. Options for these areas are: nature and hiking trails, bicycle paths, and open space.

5. GEOSYNTHETIC LINER DURABILITY

The cover system designed for the 1951 cell includes a two-component composite liner (geomembrane and geosynthetic clay) and a geonet (see Figure 3-10). The geomembrane is a 60 mil VLDPE and the geosynthetic clay liner is Gundseal® with 40 mil VLDPE as substrate. The use of geosynthetics in landfill cover systems has been increasing due to stricter regulations, the better performance offered by these materials and their economical benefits. The largest uncertainty in the use of geosynthetics is their long-term durability. The long-term durability of geomembranes has not been ascertained due to their relatively recent implementation in engineering design and the lack of endurance (time and stress wise) studies performed on them. Since regulations mandate that closure and post-closure activities satisfy requirements for 30 years, environmental engineers are increasingly concerned about their long term performance.

In this chapter, the long term durability of geomembranes will be discussed because (i) they are the most commonly applied geosynthetic in cover systems, (ii) more information is available about their environmental performance and (iii) the insight acquired in this respect can be applied to other geosynthetics. This section will not address the reasons for the selection of the geosynthetic liner for the 1951 cell cover design. Readers are referred to Elias (1996) for an explanation as to why each specific geosynthetic was chosen.

In what follows, an overview of geomembranes used in landfill cover systems as well as their properties will be presented. Then, the major degradation processes that affect geosynthetic materials, along with synergistic effects will be explained. This will be followed by an explanation of the testing methods used to assess the durability of geomembranes. Finally, the durability of the geosynthetics used for the 1951 cover system will be discussed.

5.1 Overview of Geomembranes

Geosynthetics are most commonly applied to landfills in the form of geomembranes. Geomembranes are flexible, thin sheets of thermoplastic polymeric materials that have an extremely low permeability to fluids (Sharma, 1994). There are five types of geomembranes used for pollution control: semicrystalline, flexible and reinforced thermoplastic geomembranes; thermoset elastomers and polymer-modified bitumens (Koerner, 1991). The latter two are rarely used in the United States (Koerner, 1991 and USEPA, 1991). Semicrystalline thermoplastic geomembranes include high-density polyethylenes (HDPE), while flexible (low crystalline) thermoplastic geomembranes include polyvinyl chlorides (PVC), chlorinated polyethylenes (CPE), chlorosulfonated polyethylenes (CSPE) and very low density polyethylene (VLDPE). All of these geomembranes can be seamed by thermal methods. The available reinforced flexible (low crystalline) thermoplastic geomembranes are CPE-R, CSPE-R and an ethylene interpolymer alloy called EIA-R. Reinforcements are either by internal scrim or by spread coating (Koerner, 1991). Reinforced geomembranes can also be seamed by thermal methods. Table 5-1 presents typical formulations of the most commonly used geomembranes.

Table 5-1 Typical Formulations of Geomembranes (USEPA, 1991)

Geomembrane Type	Resin (%)	Plasticizer (%)	Carbon Black and/or Filler (%)	Additive (%)
PVC	45-50	35-40	10-15	3-5
CSPE-R	45-50	2-5	45-50	2-4
EIA	70-80	10-25	5-10	2-5
VLDPE	96-98	0	2-3	1-2
HDPE	97-98	0	2-2.5	2-1

5.2 Properties of Geomembranes

This section includes a basic description of geomembrane properties. This description should provide a general understanding of geomembrane properties, and is based on material presented in Koerner (1994). Referred tests are based on standards from the American Society for Testing and Materials (ASTM).

5.2.1 Physical Properties

Physical properties are defined for uninstalled and relaxed geomembranes. The properties are defined as follows:

- Thickness: most geomembranes today are 20 mils or thicker. The ASTM D5199 test is used to measure geomembrane thickness.
- Density: the density of a geomembrane is dependent on the base material from which it is made. Its range falls between 0.85 and 1.5 g/cc. Varieties include very low-density, low-density, linear low-density, medium-density and high density. The ASTM test method D792 and D1505 can be used to determine density. Commercially available HDPE geomembranes have a density ranging from 0.934 to 0.938 g/cc.
- Melting Flow Index (MI) Testing: the test controls polymer uniformity. It relates to the flowability of the polymer in its molten state. The ASTM D1238 test method is used to determine this value.
- Water Vapor Transmission: provides an assessment of the relative impermeability of geomembranes. The ASTM test method E96 is used to determine geomembrane water vapor transmission, permeance and permeability.
- Solvent Vapor Transmission: this parameter provides an assessment of the relative impermeability of geomembranes with respect to different solvents, since polymers may show selectivity as to which solvent they transmit. The ASTM test method E96 is also used to determine a value for the geomembrane solvent vapor transmission.

5.2.2 Mechanical Properties

Mechanical properties are used to define the strength of polymeric sheet materials. The major mechanical properties and applicable tests for their measurement are:

- Tensile Behavior: tests are performed on small samples and are used for quality control and quality assurance. The relevant tests include index, uniform width and axi-symmetric tensile behavior. Data from these tests serve to model possible geomembrane behavior in the field.
- Seam Behavior: seams are often weaker than the geomembrane, therefore it is necessary to study their behavior separately. Seam tests include shear, peel and a combination of both. The ASTM tests D4437, D3083, D751, D4437 and D413 are used to assess seam behavior.
- Tear Resistance: the measurement of tear resistance is useful in specifying handling and installation requirements for geomembranes. The thicker the geomembrane, the higher its tear resistance. Tests performed to examine tear resistance include ASTM D2263, D1044, D751, D1424, D2261 and D1938.
- Impact Resistance: an assessment of this property is necessary to determine geomembrane resistance to the possible penetration of falling objects. Tests performed are ASTM D1709, D3029 D1822, D746 and D3998.
- Puncture Resistance: large stones, sticks or debris may puncture the geomembrane after the cover material is in place. Thus, assessing a geomembrane's resistance to this type of stress is necessary. Tests performed for puncture resistance are ASTM D5494 and D4833.

- Geomembrane Friction: interfacial friction between a geomembrane and other surfaces is important in avoiding the sliding of surfaces that lead to failure. Many studies have determined friction values between different geomembrane and surfaces.
- Stress-Cracking: bent strip and constant load tests exists to assess a geomembrane's stress cracking capacity.

5.3 Degradation Processes

There are a variety of degradation processes that affect geomembranes. Geomembranes are composed of polymers, which have an elongated molecular structure. Degradation cuts across the length of this structure in a process known as chain scission (USEPA, 1989). The more chain breakage's that occur, the more the polymer is degraded by loss of strength and elongation. Many of the degradation processes are slowed in cover system geomembranes by the fact that they are buried, reducing exposure to the environment. In what follows, a description of the major degradation processes will be discussed individually. In the field, these processes would not occur individually, so section 5.4 will discuss synergistic effects associated with degradation.

5.3.1 Ultraviolet

All polymers are susceptible to degradation when exposed to ultraviolet light through the process of photooxidation. Short wavelength energy from sunlight penetrates the polymer structure, causing chain scission and bond breaking (Koerner, 1994). The wavelength spectrum that causes degradation is 310 - 380 nm (USEPA, 1989). Options to minimize the effects of UV degradation are the addition of carbon black to the polymer formula, since it retards degradation, and the addition of chemical stabilizers such as scavenging agents (USEPA, 1991). A good practice to reduce UV effects is to cover the geomembrane with the overlying cover material as soon as it is seamed and inspected.

5.3.2 Radiation

Radiation degradation is of concern in radioactive waste facilities. The basic mechanical short-term properties of a typical polymer start to change at a total radiation dose between 10^6 and 10^7 rads (Koerner, 1991). In comparison, the lethal dose for humans is 100-200 rads (Koerner, 1991). Radiation degradation is not of great concern in practice, since geomembranes are seldom used in the containment of radioactive waste. Possible low-level radioactive material (for example, medical waste) present in the landfill should theoretically pose no threat to the geomembrane, but further studies are needed in order for this claim to be made with certainty.

5.3.3 Chemical

Geomembranes are susceptible to a variety of chemicals. Therefore, it is very important to determine which type of chemicals will be present in the waste and to choose a geomembrane that is not degraded by these chemicals. The EPA has developed a test protocol called EPA 9090 testing for assessing chemical resistance. Chemical resistance has been widely studied and manufacturers and fabricators have developed chemical resistance charts that list generic chemicals against many common geomembranes. While testing is necessary for liners beneath the waste that come in contact with leachate, the closure liner should only interface with water, which is derived from seepage through the cover soil placed above it (USEPA, 1991). Therefore, chemical degradation is of little concern in geomembranes used for cover systems.

5.3.4 Swelling

Swelling occurs when polymers are exposed to any liquid. This swelling occurs because the polymer accepts the liquid into its molecular structure. Even though swelling does not necessarily lead to degradation, a small loss in modulus and strength may be the first stage of degradation (Koerner, 1991). Also, swelling may cause secondary actions that could lead to other synergistic effects (USEPA, 1991). As a quality control method, tests at the time of installation for water absorption are usually performed. As a point of reference, HDPE generally swells the least and PVC the most (USEPA, 1991).

5.3.5 Extraction

Extraction occurs when a polymer loses one or more of its components, usually those compounded with plasticizers and/or fillers. Extraction may occur via a diffusion mechanism, where plasticizers leach out of polymers leaving a tacky substance on the surface of the material (USEPA, 1989). Extraction would decrease the elongation capability of the geomembrane with respect to the tension, tear and puncture modes of geomembrane failure. The long term behavior of an extracted geomembrane is unknown. Available tests that estimate extraction are ASTM D3083 for water extraction and ASTM D1203 for volatile loss.

5.3.6 Oxidation

Oxidation leads to the long-term, large scale degradation of geotextiles (Koerner, 1991). The steps in the oxidation process are as follows (USEPA, 1989):

- Heat liberates free radicals;
- Oxygen uptake occurs;
- Hydroperoxides accelerate uptake;
- Hydrogen ions attach to tertiary carbons which are most vulnerable;
- Subsequent bond scission occurs.

This process can be represented with the following reaction (Koerner, 1994):

$$R^{\bullet} + O_2 \rightarrow ROO^{\bullet}$$
$$ROO^{\bullet} + RH \rightarrow ROOH + R^{\bullet}$$

where:

$R^{\bullet}$ = free radical

$ROO^{\bullet}$ = hydroperoxy free radical

RH = polymer chain

ROOH = oxidized polymer chain

Oxidative degradation of geomembranes can be minimized by avoiding geomembrane contact with oxygen and by reducing geomembrane contact with sunlight. Both conditions are satisfied in a cover system since the geomembrane is buried. Exposed geomembranes, such as those in side-slopes, may be susceptible to this type of degradation. As another method of control, manufacturers add antioxidation additives to scavenge these free radicals in order to interfere with the oxidation process (Koerner, 1994).

5.3.7 Biological

Laboratory and field tests have demonstrated that biological degradation in polymer resins from bacteria and fungi are very unlikely (USEPA, 1989). Basically, this event does not take place since the microorganisms have to attach themselves to the polymer and find the end of a molecular chain, which is unlikely to occur. Nevertheless, microorganisms may cause clogging and blinding of flow through or within the geosynthetic (Koerner, 1994). Two tests can be used to detect this type of degradation:

ASTM G21 deals with resistance of plastics to fungi and ASTM G22 deals with resistance of plastics to bacteria.

Another major concern is the burrowing of animals. Theoretically, only materials harder than the burrower's tooth enamel or claws can survive an attack, but the degree of vulnerability is unknown. In general, it is believed that the stronger, harder and thicker the geomembrane is, the better its resistance to animal attack (Koerner, 1994). If burrowing animals are common on the site, using a rock "bio-barrier" above the geomembrane may decrease the likelihood of animal attacks (USEPA, 1991).

5.3.8 Environmental

A variety of environmental factors may affect the integrity of the cover system. Possible changes to the cover soil may compromise the behavior of the geomembrane by exposing it to the environment. Mechanisms that may affect the cover are: erosion by wind and water, root penetration and accidental or intentional intrusion. This effects are eliminated with an effective implementation of the post-closure management plan such as that presented in Chapter 3.

5.4 Synergistic Effects

The degradation mechanisms presented in Section 5.3 may interact and cause complex effects. These synergistic effects accelerate the degradation of polymeric substances. Three effects will be discussed in this section: changes in temperature, applied stresses and long term exposure.

5.4.1 Changes in Temperature

All the degradation processes, except biological and environmental, presented in Section 5.3 are accelerated with an increase in temperature. The largest database of information collected about degradation at elevated temperatures has been for ultraviolet degradation (Koerner, 1991). Elevated temperatures effects are of greater concern in the southern states, but some researchers have demonstrated that some geomembranes can withstand a maximum temperature of 160 °F. Effects are mitigated once the geomembrane is buried, since it is not exposed to direct sunlight. Freeze-thaw cycling may also compromise the performance of geosynthetics. But, as stated in Section 3.4.2.6, freeze-thaw cycling effects on polymer strength have proven to be insignificant.

5.4.2 Applied Stresses

Geomembranes are under different stresses in field conditions, contrary to the ideal stresses in testing conditions. Modeling should occur to properly assess the behavior of the geomembrane under the following stresses: compressive, tensile, shear and out-of-plane bending stresses (USEPA, 1991). The problem with such modeling is that simulating such stresses is very difficult, sometimes cost-inhibitive and many assumptions have to be made in order to predict their field behavior.

Nevertheless, stress effects need to be somehow estimated. An important stress-induced mechanism that can be tested is creep failure. It is defined as the deformation of a geosynthetic over a prolonged period of time under constant stress. The test consists of suspending a load from an 8-inch wide tensile test specimen and measuring its elongation over time. The effects of creep can be minimized by selecting materials in which the allowable stress compared with the actual stress gives a high factor of safety. Of course, the problem is estimating the actual stress in the field.

In addition, tests also exist for estimating stress cracking. Stress cracking is defined as a brittle failure that occurs at a stress value less than a material's short-term strength. The "Bent Strip Test" (ASTM D1693) and the "Environmental Stress Rupture Under Tensile Load Test" (ASTM D2552) exist to test for stress cracking performance. These tests have been criticized for many inconsistencies in their assumptions and protocol (USEPA, 1991).

The main conclusion from stress behavior analyses is that the point of maximum vulnerability are field seams. Research is ongoing to investigate this phenomenon (USEPA, 1991). For now, quality control seems to be the best retardant in this respect.

5.4.3 Long Exposure

Long term exposure can increase the effects of the above mentioned degradation processes beyond their expected characteristics (Koerner, 1991). Currently, the effect of changes in surface texture or in macro-/microscopic characteristics in polymer behavior is difficult to ascertain and has not been quantified.

5.5 Testing and Predictive Methods

Researchers have developed a variety of testing methods to predict degradation and expected lifetimes. In this section, the three most widely used testing methods for geomembranes will be explained. These are Arrhenius modeling, Hoechst multi-parameter prediction and case histories. Of these, Arrhenius modeling is the most popular.

5.5.1 Arrhenius Modeling

Arrhenius modeling assumes that elevated temperatures can be used to simulate time at a site-specific (and lower) temperature. This assumption is referred to as a temperature-time superposition concept (USEPA, 1991). Koerner (1994) explains the test as follows. An experimental chamber, Figure 5-1, superimposes compressive stress, chemical and oxidative exposure, elevated temperature and long testing times.

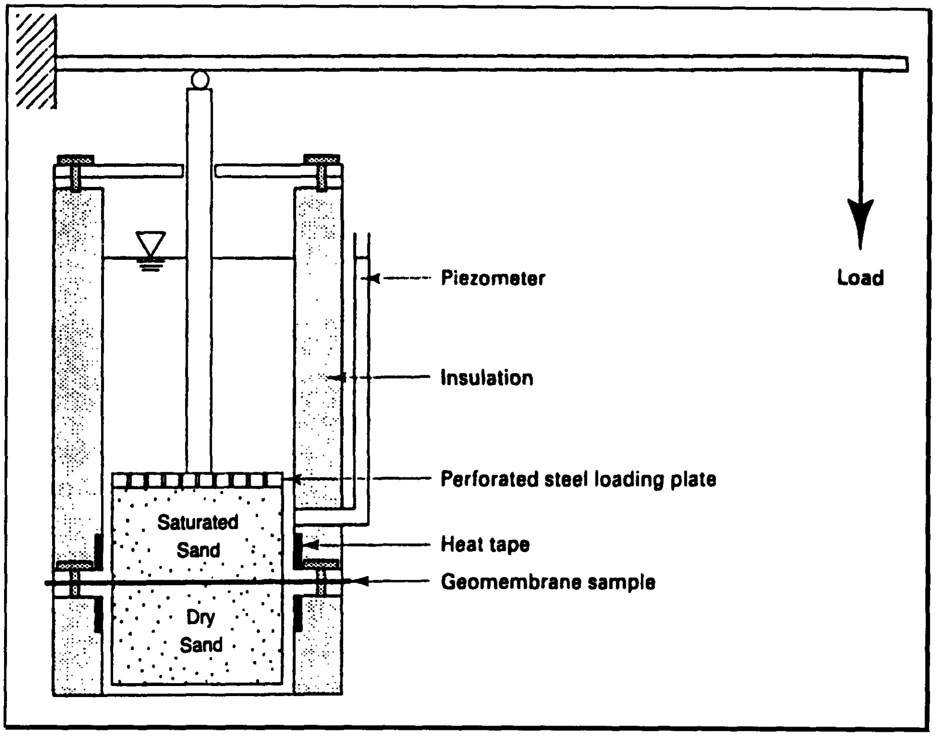


Figure 5-1 Incubation Unit for Accelerated Aging (Koerner, 1994)

A group of columns can be used to test a sample, with each column being kept at a different temperature. Samples can then be removed periodically and evaluated for changes in physical, mechanical and chemical properties. Their behavior, if then plotted, would look like that presented in Figure 5-2 (a). Then, if a 50% reduction in the measured property is chosen as a design criterion, another plot can be made which would look like Figure 5-2 (b). This is termed the Arrhenius curve, which plots the inverse temperature against the inverse reaction rate.

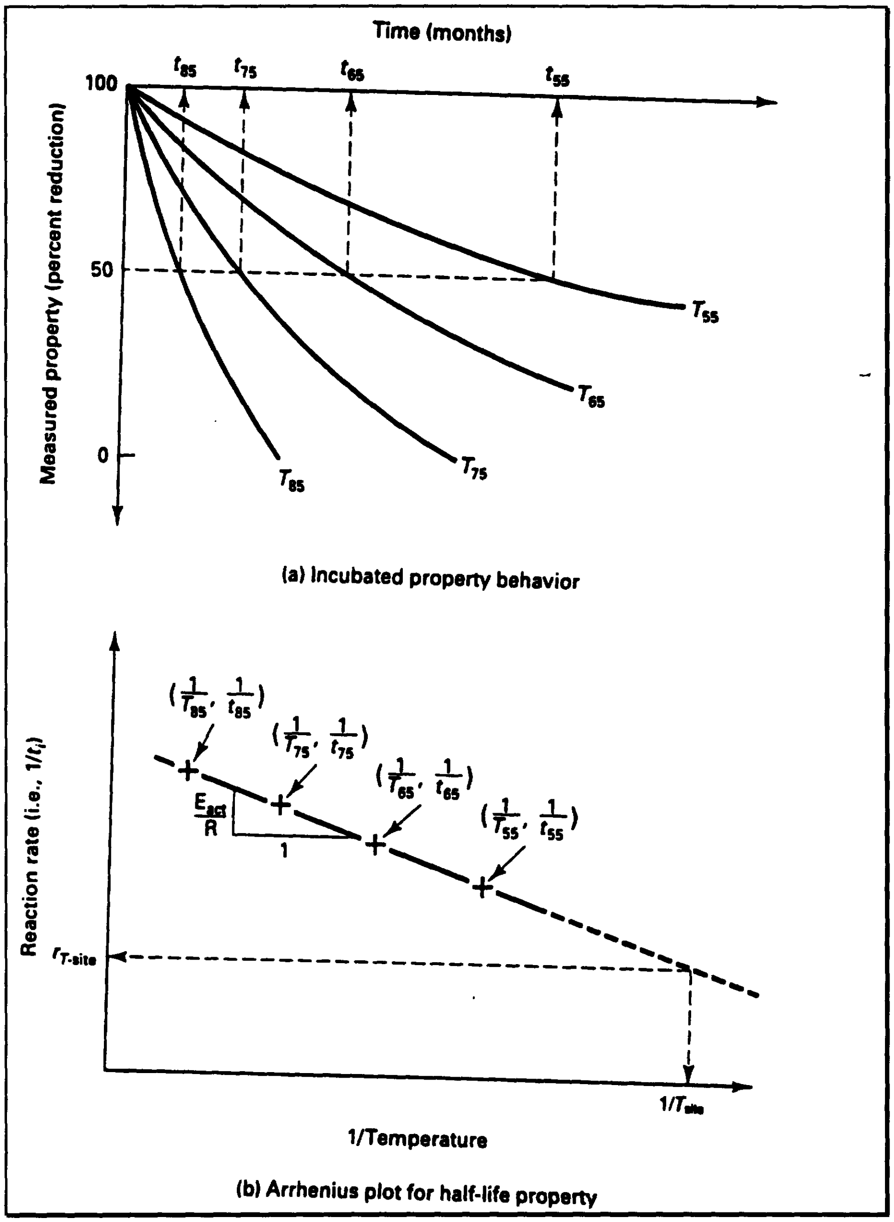


Figure 5-2 Arrhenius Modeling For Lifetime Prediction Via Elevated Temperature Aging (Koerner, 1994)

The slope of the line is the activation energy divided by the gas constant. From this curve, the lower site-specific temperature can be extrapolated and is shown in Figure 5-2 (b). The equation for extrapolation is:

$$\frac{r_{T\text{ - }test}}{r_{T\text{ - }site}} = e^{-\frac{Eact}{R}\left[\frac{1}{T-test}-\frac{1}{T-site}\right]}$$

where:

E_{act}/R = slope of Arrhenius plot

T-test = the incubated (high) temperature

T-site = the site-specific (lower) temperature

$r_{T\text{-test}}$ = the reaction rate for half-life at incubated temperature

$r_{T\text{-site}}$ = the reaction rate for half-life at site temperature

From this equation, the reaction rate for half-life at the site can be estimated.

Problems with this technique lie in the fact that a constant activation energy is assumed and that experimental inaccuracies in the handling of the apparatus are possible (Koerner, 1991).

5.5.2 Hoechst Multi-Parameter Prediction

The explanation for the Hoechst multi-parameter method is acquired from USEPA (1991). For a more detailed explanation, readers are referred to Kork et al. (1987). The test consists of using a number of experimental and field-measured response curves to predict the lifetime of the geosynthetic. Figure 5-3 presents such curves. Curve (a) is constant stress, (b) is stress relaxation and (c) is the field measured strain curve. By superposition of the proper temperature response curve and the appropriate strain response curve (laboratory and field), the lifetime of the geomembrane can be predicted under the following assumptions:

- No additional stress relaxation (curve a).
- Intermediate stress relaxation (curve b).
- Full stress relaxation (curve c).

Results are shown in Figure 5-3 (d). The drawback to this technique is the amount of experimental and field data needed.

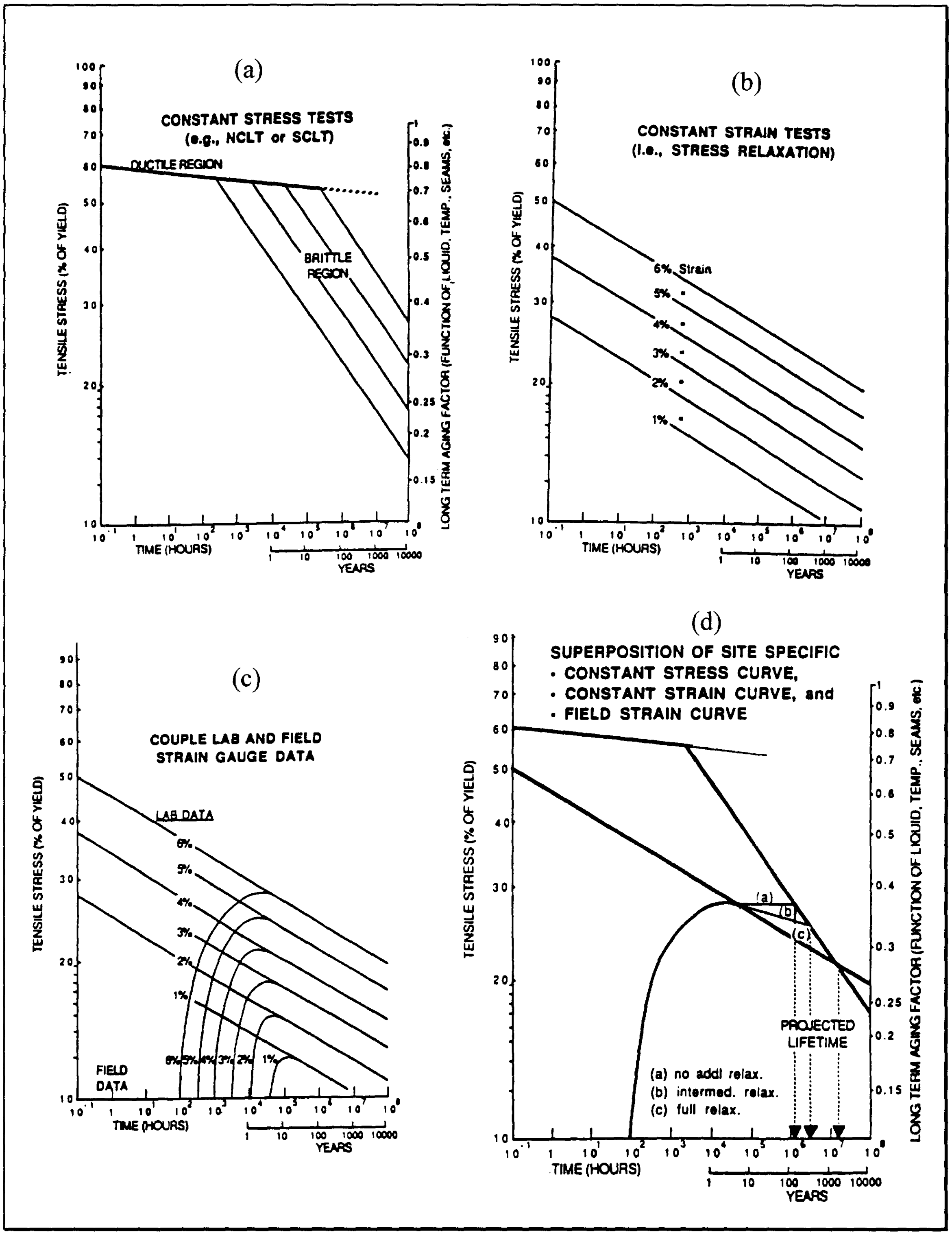


Figure 5-3 Hoechst Multi-Parameter Curves

5.5.3 Case Histories

At present time, case histories serve as the best estimate of field performance of geomembranes. A couple of years ago, landfill owners started burying geomembrane samples (coupons) and exhuming them annually for evaluation (Koerner, 1991). In addition, thorough investigation and documentation of field failures serve to assess performance under field conditions. These type of studies are essential to properly determine the field behavior of geomembranes.

5.6 Application to the 1951 Cell

Estimating the durability of the 60 mil VLDPE geomembrane in the cover system for the 1951 cell is not an easy task. The fact that the use of geosynthetics in cover systems is a fairly recent event, coupled with the little research that has been performed to date on the long term durability of geosynthetics, makes a precise prediction of durability impossible. Nevertheless, from the current laboratory research and limited field studies, we can ascertain that geomembranes used for cover systems should have a fairly long life. The fact that the geomembrane is buried in the cover soil retards many of the degradation pathways discussed earlier, such as UV and oxidation degradation. If the post-closure management plan presented in chapter 3 is carefully followed, exposure of the geomembrane to the environment should not occur, thus minimizing the chance of degradation. Another factor that should extend the life of the geomembrane is the fact that it will only be exposed to seeping water and not to possibly degrading leachate.

Also, tests have demonstrated that geomembranes are not affected by freeze/thaw cycling, which is a concern in the state of Massachusetts. Finally, proper quality control and assurance tests done at the time of installation should ensure a longer life for the geomembrane.

It seems that the greatest vulnerability of geomembranes lie in their in its reaction to applied stresses. Further research is necessary in this area to accurately predict the lifetime of a geomembrane under different stress conditions. Laboratory testing and prediction techniques are very useful in providing a ballpark figure of the behavior and life expectancy of the geomembrane, but field scale results have to be evaluated. Future results should shed new light on the long term behavior and life expectancy of geomembranes. But for now, it seems reasonable to assume that a geomembrane will have a lifespan of more than the required 30 years with exceptional performance.

6. CONCLUSION

In this thesis, all aspects of the post-closure of a landfill were discussed. First, a post-closure management plan was created for the 1951 cell based on the cover system designed by Elias (1996). Then, possibilities for the post-closure land use were presented. Finally, geomembrane durability was discussed. Following, are the main conclusions reached from these discussions.

The major components of a post-closure management are environmental monitoring systems (groundwater, air quality and surface water monitoring), maintenance of cover and vegetation and possible corrective actions. Monitoring and sampling plans were developed for each of the environmental monitoring systems. As part of the groundwater monitoring system, three groundwater monitoring wells were recommended to be installed in the vicinity of the 1951 cells, to satisfy the requirement that at least three wells should be placed less than 150 meters from the boundary of the cell. In addition, already existing monitoring wells are to be incorporated into the monitoring program. For air quality monitoring, one additional gas probe was specified across Herbert Road at a distance of 650 feet from already present gas probe #12 and #1 (Figure 3-10). This distance is based on regulations that state that for an area where there is no public access, the average spacing between probes shall be 650 feet.

As part of the maintenance program, a detailed plan was developed covering the following aspects:

- Inspection schedule: this schedule specified the frequency of inspection for the final cover, vegetative cover, drainage system, monitoring systems, surveyed benchmarks and security systems (Table 3-3).
- Maintenance of cover and vegetation: this component detailed the parameters to investigate and maintain in the cover system, vegetation, soil, mowing, fertilizing, sprinkling , reseeding, freeze/thaw effects and rodent and insect control.
- Maintenance of drainage system.
- Monitoring for settlement, subsidence and displacement.
- Maintenance of environmental monitoring systems.
- Planned responses to possible occurrences.
- Maintenance of security systems.
- Submittal of Records.

It was determined, that an effective implementation of a post-closure management plan would ensure proper source containment, help assess the effectiveness of the cover system and help in the study of geomembrane performance in the field.

The alternatives for post-closure land use of the 1951 cell were also investigated. It was found that the possibilities for development were very limited. The best alternative for post-closure land use of the 1951 cell was its utilization as a passive recreational area. Options for such areas include: nature and hiking trails, bicycle paths, and open space.

The author also suggest future investigations to properly assess the public willingness to utilize an area underlained by a hazardous waste landfill.

Finally, this report investigated the durability of the geomembranes utilized in the cover system. Major properties of geomembranes as well as degradation processes and testing methods were presented. It was found that proper methods for predicting geomembrane durability in the field do not exist at this time. Nevertheless, from the current laboratory research and limited field studies, we can ascertain that geomembranes used for cover systems should have a fairly long life. The fact that the geomembrane is buried in the cover soil retards many of the degradation pathways such as UV and oxidation degradation. If the post-closure management plan presented in chapter 3 is carefully followed, exposure of the geomembrane to the environment should not occur, thus minimizing the chance of degradation. Another factor that should extend the life of the geomembrane is the fact that it will only be exposed to seeping water and not to possibly degrading leachate. Also, tests have demonstrated that geomembranes are not affected by freeze/thaw cycling, which is a concern in the state of Massachusetts. Finally, proper quality control and assurance tests done at the time of installation should ensure a longer life for the geomembrane.

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8. APPENDIX A: Post-Closure Management Log Form

POST-CLOSURE INSPECTION CHECKLIST FOR THE 1951 CELL AT THE MMR

INSPECTION DATE: ______________________

INSPECTORS: ______________________

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INSPECTION ITEMS	STATUS	DATE CORRECTED	COMMENTS
SITE SECURITY			
Condition of fences and gates			
Signs of unauthorized access/vandalism			
Other			
FINAL COVER			
Condition of vegetation			
Free of woody vegetation			
Mowing satisfaction			
Need for reseeding and fertilizing?			
Condition of soil			
Rodent and insect presence			
Freeze/thaw effects?			
Ponded water			
Other			
EROSION AND SEDIMENTATION CONTROL			
Slopes satisfactory?			
Perimeter Ditches			
Storm water basins			
Eroded or bare spots?			
Other			
GROUNDWATER AND LANDFILL GAS MONITORING			
Wells and probes marked and locked			
Well and probe seals intact			
Are wells and dedicated sampling equipment functional and in good repair?			
Signs of vandalism?			
Date of last sampling			
Any parameters exceeded in last sampling			
Other			
LANDFILL GAS VENTING (LFG) SYSTEM			
Has settlement affected vents?			
Evidence of LFG venting			

Evidence of LFG odors			
Other			
SETTLEMENT/SUBSIDENCE			
Are settlement platforms and benchmarks intact?			
Date of last settlement reading/survey			
Is ponding occurring on cap or in swales			
Low areas/depressions			
Ponding of water			
Other			
STORMWATER MANAGEMENT SYSTEM			
Channels			
Erosion/condition of lining			
Sediment buildup			
Differential settlement/ponding of water			
Diversion berms in place where needed			
Excessive vegetation of other blockages			
Catch Basins			
Cleaning			
Structural condition			
Grates in place?			
Sediment Basins			
Cleaning			
Silt fence in place?			
Rip-rap in place?			
Outlet pipes clear and clean?			
Other			
MISCELLANEOUS			
Signs of illegal access			
Wildlife damage			
Vegetative distress			
Surface water monitoring			
Are required records being maintained			
Are ground, surface and gas monitoring being conducted in accordance with approved schedule and requirements?			
Have reports been filed with the MADEP			
Other			