SITE INVESTIGATION REPORT
HOLTRACHEM MANUFACTURING SITE
ORRINGTON, MAINE

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Section 5
Environmental Setting

5.1 Introduction

This section provides a description of the environmental setting of the site including the regional and site specific geology, hydrology and hydrogeology. The environmental setting provides the framework for evaluating the distribution of contamination and the fate and transport of contaminants.

5.1.1 Geologic History

The regional geology of the Orrington area is a product of geologic processes dominated by plate tectonics and glaciation.

The sediments which formed the rocks of the Orrington area were deposited in a sea called Iapetus which existed in the area approximately 400 million years ago (MY). The North American and European (Avalonian) continental plates were converging during Ordovician and Silurian periods (500-430 MY and 430-390 MY respectively). The sediments deposited between the two converging continental plates were then compressed and altered (metamorphosed) as the two plates collided during the Devonian period (390-345 MY). Granitic rock was formed at greater depths and the rising molten rock created the intrusive bodies which form some of the nearby mountains. The collision of the two plates thrust older rock over younger rock south of the Norumbega fault, which is located approximately two miles south of the HoltraChem Site. When the two plates split at what is now the Atlantic Ocean, part of the Avalonian plate (located between the Norumbega fault and the present coast) was left behind.

The present topography of the site and the overburden deposits are primarily a result of relatively recent glacial activity. The last major glacial event was the Wisconsin-age continental glaciation which is believed to have reached its maximum extent approximately 40,000 years ago. At this point the ice was more than 10,000 feet thick and extended to George's Bank, approximately 180 miles to the southeast.

As the glaciers melted, the load of rock and soil they transported was deposited on land as glacial tills and ice contact deposits. The material ground beneath the glacial ice resulted in a very dense layer known as lodgement till or hardpan. The material carried along on and in the ice which was deposited as the ice melted is known as ablation till. Glacial tills ground beneath or dropped by glacial ice typically form hummocky terrain.

The amount of water bound in glacial ice lowered sea level to almost 400 feet below its current position. At the same time, the weight of the ice depressed the earth's crust beneath the glaciers. The ice began to retreat approximately 20,000 years ago. By about 14,000 years ago, the edge of glacial ice was just offshore of the Maine coastline. As the glaciers melted, sea level rose and the earth's crust rebounded. However, isostatic rebound was slower than sea level rise, and the sea transgressed far inland of the current coastline. Glacially derived sediments were deposited in the near shore sea. The glacio-marine sediments have been found as far inland as Medway (north of Bangor) on the Penobscot River and as high as 400 feet above current sea level. The Orrington area was inundated after the glacial ice melted, and marine sediments are found locally on top of glacial tills.

As the earth's crust continued to rebound, the sea receded and present day coastal Maine emerged from the water. During the emergence, the sea reworked some of the marine sediments and glacial tills. Wave action winnowed fine grained material (silt and clay) from glacio-marine deposits and glacial till and redistributed sand and gravel. Some of the onsite and local sand and gravel deposits may be a result of these processes. After the sea retreated, the processes of erosion from freezing and thawing, wind and rain continued to work on the landscape to bring it to its present day appearance.

5.1.2 Bedrock Units

<u>Rock Type</u>

The bedrock geology of the Orrington region is characterized by a northeasterly trending suite of Ordovician/Silurian-age metasediments (metamorphosed sedimentary rock) referred to as the Vassalboro Formation. The composition of the sedimentary rock from which they were formed was typically calcareous sandstone, and interbedded sandstone and impure limestone. The Vassalboro Formation is bordered to the south by the Devonian-age metasediments of the Bucksport Formation. Devonian intrusive rocks that are common to the Winterport and Mt. Waldo granitic plutons are found to the south and east of the site area.

The metasedimentary strata in the Orrington region are believed to have been subjected to two deformational events: Acadian folding and late stage Acadian orogenic (mountain building) movement and plutonic emplacement. The present mineralogic assemblages and dominant structural trends of the metasediments are interpreted to be the result of the orogenic events. The degree of metamorphism is moderate, and is characterized as the greenshist facies due to the predominance of the green mineral chlorite.

Topography

The bedrock topography of the Orrington area is a result of faulting and folding, uplifting and downwarping of the bedrock by tectonic forces and intrusion of ~~the~~ granitic rock. The forces of glacial ice, freeze-thaw, wind and water preferentially eroded softer rock and had less effect on more resistant rock. The Maine coastal region south of Bangor is typified by relief of less than 300 feet except for the more resistant granitic intrusions which form the mountains along the coast south of the site.

Structure

Upward folding of local rock resulted in the Liberty-Orrington antiform. This antiform and the rocks at the site have been cut by the Norumbega fault and its associated splays. The main zone of the fault is located approximately two miles south of the site area, but a splay cuts across the site.

Fracture trace analysis performed by Acheron identified three prominent lineament directions: N72-85W, N45-52W, and N28E (see Figure 4-6, Appendix B). These lineament directions are in general agreement with the regional lineaments depicted on the regional photolinear map (Figure 4-5, Appendix B).

5.1.3 Overburden Units

The surficial geology of the Orrington region reflects the region's glacial and post-glacial depositional history.

Glacial deposits include lodgement and ablation till, and ice-contact deposits including eskers and kames. Glacial tills typically contain a wide variety of grain sizes from clay and silt up to boulders. Tills generally exhibit low hydraulic conductivity (permeability) due to their high content of fine grained material (silt and clay). Typical hydraulic conductivities range from 10 E-7 to 10 E-5 cm/sec. Lodgement till typically contains more clay and is usually denser than ablation till due to its compaction beneath the great weight of the ice. Because of its density and high percentage of fine sized particles, lodgement till typically exhibits very low hydraulic conductivity. Ablation till typically contains more silt and sand and occasionally contains pockets of water-washed sand and gravel.

Glacial till at the HoltraChem site was laid directly atop bedrock by the glacier itself, causing a thin veneer in the uplands and thicker deposits in the lowland areas. As the glacier melted during the deglaciation period, ice-contact and glacio-fluvial deposits, most notably sand and gravel, were laid down by pro-glacial and subglacial streams. These deposits often parallel modern drainage systems, a phenomenon is observed along the length of the Penobscot River. Hydraulic conductivities of the sand and gravel deposits typically range from 10 E-4 to 10 E-2 cm/sec. Some gravel deposits exhibit hydraulic conductivities as high as 10 E-1 cm/sec. Hydraulic conductivities of these deposits are determined by grain size and sorting.

Marine transgression capped the glacio-fluvial deposits with glacio-marine silt and clay deposits, which display distinctly poor permeability (typically 10 E-6 cm/sec or lower). These deposits are known throughout coastal Maine as the Presumpscot formation. Glacial till is usually observed at the surface in the uplands of the Orrington area. In the lowlands, the till deposits thicken and are often overlain by late-glacial sand and gravel or marine silt and clay deposits. Occasionally the tills or marine sediments, especially on the ridges, were reworked by the sea as the land rebounded and emerged from the water. These deposits resemble beach sands and have relatively high hydraulic conductivities.

5.2 Regional Hydrology and Hydrogeology

5.2.1 Climate - Precipitation

The climate in the Orrington area is temperate, with cold winters and mild summers. Temperatures range from sub-zero (Fahrenheit) in mid-winter to the mid-to-upper eighties in the summer months. Precipitation averages approximately 40.25 inches per year, 3.35 inches/month. The months with the highest precipitation are typically November and December (average 4.92 and 3.88 inches, respectively). The driest months of the year are typically August (average 2.85), and March and May (both average 2.97 inches). The primary growing season occurs after snow melt in April and extends through August. Evapotranspiration, the combined processes of evaporation and transpiration from plants, is greatest during the months of May and June and may account for the return of much of the water which infiltrates the root zone to the atmosphere. An average of 15% of the available annual precipitation (approximately 6 inches) is anticipated to infiltrate to groundwater.

The prevailing wind direction at the Orrington plant is from the south and south west. During the spring and summer months, thermal energy created by warmer temperatures on the land relative to the cold coastal water create updrafts which pull cooler air up the Penobscot River Valley. During the winter months, wind directions are likely to be more variable with storms coming in from the south and west and occasionally from the northeast. Weather data compiled at Bangor Dow field, including a wind rose, is provided in Appendix E.

5.2.2 Surface Water Bodies

The HoltraChem plant is located on the east bank of the Penobscot River, approximately 5 miles south of Bangor. Below Bangor, the river is tidal with an average range measured at Hampden of

12.8 feet. In the plant area the river is approximately 30 feet deep and is essentially fresh water. An occasional salt water wedge is present along the bottom during periods of high tides and low river flows. Salinity soundings were performed during the SI and no salt water wedge was observed. However, brackish water was reportedly produced from onsite wells adjacent to the river during high tides.

The drainage area of the Penobscot River above the HoltraChem site is approximately 8,570 square miles. The maximum flow recorded at the Eddington gage was 153,000 cubic feet per second (cfs) in April 1982. The Eddington gage is located approximately 10 miles upstream of the HoltraChem Site, but provides a good indication of the river conditions at Orrington. The average flow of the Penobscot River measured at the Eddington gage is approximately 16,400 cfs. The 7 day -10 year low flow (7Q10 flow) at the Eddington gage is approximately 4,000 cfs. During the 1995 SI river sampling, the average flow was 10,000 cubic feet per second. During the latter part of that summer, the flow was approximately 3,000 cubic feet per second due to an extended drought. Surface water flows during the dye study performed in 1998 ranged between 4000 and 7000 cfs.

The river channel in the vicinity of the HoltraChem site is characterized by three distinct environments. To the north of the plant, the river flows southeasterly along a bedrock outcrop. In this stretch, the bedrock outcrop forms the shoreline and there are no deposits of sand or gravel except for a small bank at the mouth of a gully north of Landfill 4. After rounding the western end of the bedrock ridge, the river turns south and a steeply sloping sand and gravel bank is present extending from the base of Landfill Area 1 to a cove located at the southern boundary of the plant property.

A regional stream, the Souadabscook, enters the Penobscot River in Hampden, opposite the HoltraChem plant. The Souadabscook drains primarily agricultural land west of Bangor.

5.2.3 Water Bearing Units

Groundwater is present in both the overburden and bedrock. However, with the exception of local deposits of sand and gravel, the majority of the overburden deposits are till and are not typically permeable enough to be developed for groundwater supplies.

Because the crystalline bedrock of the area has very low primary porosity (typically < 2-3%), groundwater in bedrock is present primarily in fractures. Residential wells are typically installed into bedrock with surface casings sealing off the overburden deposits. Wells in the vicinity of the HoltraChem site range from 90 to 365 feet deep. The depths of the wells are often determined by the number of water bearing fractures encountered and the storage capacity required of each well.

5.2.4 Groundwater Flow

The Penobscot River is the regional discharge point for groundwater flow. Recharge areas potentially extend to the local drainage divides, located approximately 10 miles to the east. The amount of recharge to overburden and bedrock is primarily dependent on the permeability and slope of the surface deposit. Steeply sloping surfaces of low permeability will limit infiltration while permeable, relatively level deposits will enhance infiltration. Infiltration rates in glaciated terrain typically range from 35% of available runoff (precipitation - evapotranspiration) over till deposits to up to 90% over sand and gravel deposits. Based on the average annual rainfall and evapotranspiration percentages calculated for the Bangor/Orrington area, infiltration to groundwater ranges from approximately 5 inches per year over tills to approximately 12 inches per year over sand and gravel. The majority of the ground surface in the Orrington area is covered by till. A downward vertical gradient is typical in recharge areas.

Along the eastern bank of the river, groundwater flows from east to west toward the river. As the groundwater approaches the discharge point, an upward vertical gradient will predominate. This upward vertical gradient has been observed in bedrock and overburden well clusters on the HoltraChem site.

5.2.5 Water Quality

Groundwater

The bedrock groundwater in the Orrington area is used as a drinking water source. In general, the water quality is adequate for residential use. The bedrock groundwater is often characterized as hard, typically with 1 to 2 grains per gallon (17 to 34 mg/l) hardness (as $CaCO3$) and sometimes measuring up to 10 grains/gallon (171 mg/l). Typical water problems are related to high concentrations of iron (2-5 mg/l) and to a lesser extent manganese ($\leq$ 1 mg/l). Some wells yield very high levels of iron and manganese (e.g. the Norlens Water Treatment Service well which contained 28 mg/l iron and 18 mg/l manganese when sampled in January 1998). These wells are typically treated with water softeners. Elevated salt concentrations, either due to saltwater intrusion or road salting, are occasionally a problem (Tom Demaso, Norlen's Water Treatment Service, Orrington, Maine, November 1998). During sampling of the residential wells on Ferry Road, measurements were obtained for salinity and specific conductance. Salinity values ranged from 0.00% to 0.06%, indicating that some wells yield slightly saline water.

Little information is available regarding the use of overburden groundwater as a drinking water supply. Prior to obtaining Bangor City water, the Town of Hampden operated a gravel packed well near the bank of the Souadabscook Stream. This well developed iron and manganese problems which would have required Hampden to treat the water. Rather than building a treatment plant, Hampden began purchasing Bangor water. They still operate the gravel packed well to sell water for commercial uses. The drilling water for the SI was obtained from this well to prevent the possibility of introducing chloroform, which is often present in chlorinated municipal water supplies, into the subsurface.

Surface Water

The Penobscot River in Orrington is classified as Class C in Maine's Surface Water Classification System. Class C is the third highest classification, and the waters "shall be of such quality that they are suitable for a drinking water supply after treatment, recreation in and on the water, fishing, industrial process and cooling water supply, hydroelectric power generation, navigation, and as a habitat for fish and other aquatic life. "

Just below the southern cove, along the southwest border of the HoltraChem site, the Penobscot River is classified as SC due to the increasingly brackish nature of the river. Estuarine waters are classified SA through SC. Class SC is the fourth highest classification, and the waters "shall be of such quality that they are suitable for recreation in and on the water, fishing, aquaculture, propagation and restricted harvesting of shellfish, industrial process and cooling water supply, hydroelectric power generation and navigation and as a habitat for fish and other estuarine marine life.

"Discharges to Class C waters may cause some changes to aquatic life, provided that the receiving waters shall be of sufficient quality to support all species of fish indigenous to the receiving waters and maintain the structures and function of the resident biological community." (Maine Water Pollution Control Law, Section 465.4C)

A dioxin-based fish advisory for the Penobscot River has been in effect since 1989. It recommends no more than two meals of fish a month from Penobscot River waters and pertains to the reach from Lincoln (north of Bangor) to the mouth of the river (Bucksport).

A mercury based advisory currently exists for limiting the consumption of fish from all lakes and ponds in Maine. This advisory recommends that pregnant women and young children not eat fish and that others limit their intake to between 6 and 22 meals a year depending on a number of factors such as fish size, specific lake, etc.

On March 28, 1997, the MEDEP issued a fish advisory for all inland rivers and streams in the state due to elevated levels of mercury. Among its recommendations, the advisory recommends limiting fish consumption to between 1 and 2 fish meals per month for fish from the Penobscot River; pregnant women, nursing mothers and children under the age of 8 are advised not to eat any fish from lakes, ponds or rivers in the state (Maine Department of Human Services, March 1997).

5.2.6 Water Uses

The Penobscot River is used recreationally and for transportation. Pleasure craft and barges were regularly observed on the river during the course of the SI. Recreational uses include fishing and may include swimming, although the current is strong and the water temperature is cold most of the year. There is a commercial eel fishery in the reach of the river south of Bangor.

5.3 Site Geology

5.3.1 Introduction

The geology of the site is the most significant factor influencing groundwater flow and potential subsurface contaminant transport. Subsurface stratigraphy at the site was investigated by advancing twenty-two soil borings during the 1995 site investigation, and an additional 17 soil borings during the 1997 Supplemental Site Investigation. Soil samples were collected for geologic description from twelve of the borings in 1995, and ten of the borings during the fall of 1997. Monitoring wells were installed in twenty-one of the borings in 1995, and all 17 borings during 1997. Figure 3-2 shows locations of soil borings and monitoring wells. Geologic logs of soil borings advanced during the 1995 and 1997 site investigations are presented in Appendix D. To develop a geologic model of the site, information obtained during the supplemental site investigation has been combined with results of previous geologic and geophysical investigations. Since 1965, at least ten geotechnical and environmental drilling programs have been performed at the site. These programs were summarized in Section 2 (see Table 2-4). A Previous Investigation Location Plan is provided in Appendix B.

5.3.2 General Stratigraphy

Subsurface stratigraphy encountered during the recent investigation is generally consistent with stratigraphy described by CDM (1995), Acheron (1991), and with the regional stratigraphy described in Section 5.1. Geologic materials encountered during drilling included fine-to medium-grained phyllite bedrock, and overburden materials consisting of glacial till, unconsolidated glacial outwash deposits and marine sand, silt and clay. Various man-made fill deposits were also encountered. The thickness and distribution of geologic materials is controlled by the bedrock surface topography beneath the site. On the prominent bedrock ridge located north of the plant area, overburden units are relatively thin and discontinuous, with laterally variable thicknesses. Beneath the plant area, south of the bedrock ridge, greater and more consistent thicknesses of overburden deposits are present. The sediments observed adjacent to the Penobscot River are significantly different from those observed beneath the plant area or on the bedrock ridge.

The three settings outlined above allow the site to be segregated for descriptive purposes into three geologically distinct areas, termed the "ridge", "plant" and "river" areas. The boundary between the ridge and the plant and river areas is defined by the bedrock scarp running approximately west to east across the site from the Penobscot River to the flooded gravel pit east of Landfill 2. Landfills 3, 4, and 5 are situated within the ridge area. The plant area extends from the flooded gravel pit east of Landfill 2 through the manufacturing facility to the lined process lagoon. The river area extends from the lined process lagoon to the southern cove.

Bedrock

Bedrock encountered during drilling and exposed in outcrops at the site consists of light gray to gray, fine- to medium-grained micaceous phyllite, a low-grade metamorphic rock. The rock encountered at the site is consistent with the descriptions of the Vassalboro Formation in regional geologic texts and maps.

The great relief in the bedrock surface is due to the expression of a fault interpreted to exist between a deep bedrock valley beneath the plant and the bedrock ridge. The topography of the bedrock surface is presented in **Figure 5-1**. The elevation of the top of the bedrock surface ranges from Elevation -90 PD (B-320-B1) to Elevation 96.8 PD (B-303-B1). Bedrock crops out in three general areas of the site: along the Penobscot River north of the bedrock ridge, along the bedrock scarp between the ridge and the plant, and in the southern cove near the outfall of the southerly stream.

The phyllite bedrock is hard, well indurated, and slightly weathered in outcrop. During the installation of bedrock monitoring wells, the upper 5 feet of bedrock was penetrated with a roller bit, to allow permanent casing to be set. In the boring for MW-411-B1, the upper portion of the bedrock was soft enough to allow augers to penetrate approximately 4 to 6 feet into the rock. In the boring for MW-511-B1, there appeared to be a zone of fragmented bedrock in the upper 5 feet of core. With the exception of these two locations, the rock encountered during the initial 5 feet of bedrock drilling appeared to be very resistant.

Metamorphic alteration has imparted a well-developed planar foliation on the rock, resulting in anisotropic fracture patterns and cleavage. During the 1997 field season, the orientations of prominent foliation planes and fractures were measured at six outcrops on site. The average strike and dip of the foliation as measured at these outcrops are approximately N86W to S16W, and 58 to 78 degrees to the northeast, respectively. A polar projection and a map of fracture orientations are presented in Appendix E. Virtually all of the porosity of the local bedrock is assumed to be due to metamorphic foliation structures and secondary jointing within the rock. Bedrock cores obtained during drilling, and inspection of local outcrops indicate that significant fracturing occurs along foliation planes; secondary joint sets in outcrop are oriented primarily in a northeasterly direction (N15E to N60E), but these joint orientations are less consistent than the orientation of foliation planes.

5.3.3 Overburden Units

Subsurface investigations identified four general overburden units underlying the HoltraChem site: glacial till, glacio-fluvial outwash, fine-grained marine sediments, and man-made fill. The following paragraphs describe the physical characteristics and distribution of overburden units in the ridge, plant, and river areas.

Glacial Till

Overlying bedrock in most locations is a dense, gray or brown glacial till. In some locations, this till crops out at the ground surface. At other locations, the till is overlain by light brown to brown, unconsolidated mixtures of sand, silt and gravel with minor portions of clay. The stratigraphically lower "gray till" is found only in the plant area. The stratigraphically higher "brown till" is found in both the plant and ridge areas, and occasionally overlies the gray -till. A description of each of these units follows.

The gray till consists of gray, medium to very dense mixtures of silt and clay, with minor amounts of coarse- to fine-grained sand and gravel. In several new and existing borings, the upper portion of the gray till contains a higher sand and gravel content. Boulders up to 6 feet in diameter were encountered in two borings. During recent or previous investigations, geologic sampling did not encounter interbedded sand or gravel intervals within the till that could provide a preferential pathway for groundwater flow. Because of the tight, compact nature of this unit as well as the lack of coarse interbedded layers, this unit forms a low permeability impediment to vertical groundwater flow into bedrock, wherever encountered. A grain size distribution curve of a gray till sample obtained from MW-404 is provided in Appendix E.

The brown till, in contrast to the gray till, has greater vertical variability and a wider distribution of grain sizes. It consists of dense to very dense, light to dark brown mixtures of silt, sand, and gravel. Grain size curves for the brown till encountered in B-402-O1 and B-406-O1 are provided in Appendix E.

Because the till layers typically have low hydraulic conductivities, the depth and thickness of till deposits help to delineate the pathways for overburden groundwater flow. The extent and thickness of glacial till are illustrated in **Figure 5-2**. Till deposits are thickest in the bedrock valley beneath the manufacturing plant (101' at MW-404) and in the vicinity of Landfill 2 (81.5' at B-301). Till deposits are thin on the bedrock ridge and are very thin to absent beneath and northeast of Landfill 4. A boring performed by L.A Wing through Landfill 4 in 1975 did not encounter till deposits above refusal which, based on other borings, was interpreted to be bedrock. Till was not encountered above bedrock in the boring for MW-506-B1, which was installed through Landfill 4.

The thick deposits of glacial till observed beneath the plant area thin abruptly to the south and toward the Penobscot River. On the southern side of the plant, the till is very thin at B-327 and MW-504. Till is not present at MW-503, located south of the railroad spur terminus. Till is also not present in B-321-B1, nor at MW-511 or MW-505. In the western and northern portions of the plant, the till is absent at B-320-B1, adjacent to the river at the southern cove. Till is also very thin to absent adjacent to the bedrock scarp at the northern boundary of the manufacturing plant (B-315), and in MW-401-B1, at the base of Landfill Area 1.

Glacio-fluvial Outwash Deposits

Outwash deposits encountered in both the ridge and plant areas consist of interbedded, moderately stratified, heterogeneous mixtures of medium to very dense, light to dark brown, orange brown, and light gray to gray sand, with little to no silt and minor amounts of gravel and clay. Occasionally, silt or gravel content may approach 50 percent. The extent and thickness of sand, gravel, and fill deposits are shown on **Figure 5-3**.

As indicated on Figure 5-3, a narrow channel of sand and gravel is located adjacent to the bedrock scarp at the northern edge of the plant. Grain size distribution curves for two samples obtained from MW-405-B1 are provided in Appendix E. Based on geotechnical borings performed in the plant area, these deposits do not extend beneath the plant area.

Another sand and gravel deposit is present south of the plant in MW-503 and MW-504. This deposit is characterized by a medium-dense, gray-brown sand overlying a gray-brown gravel. At MW-503 the gravel directly overlies bedrock, while at MW-504 the gravel and bedrock are separated by approximately two and a half feet of dense silty till. The top of this sand and gravel deposit ranges from 31' PD (approx. 33' NGVD) in MW-504 to 59' PD in MW-503. The bottom of this deposit is approximately Elevation 26' PD in both MW-503 and MW-504.

The thickest deposits of sand and gravel occur adjacent to the Penobscot River. The maximum thickness is observed in B-320-O1, where it is approximately 94 feet thick and extends from 10 feet below ground surface to a depth of approximately 104 feet (-90 feet NGVD). In B-326-O1 this deposit extends from 34 to 64 feet below ground surface (elevation 0 to elevation -30 NGVD). A grain size distribution for the sand and gravel deposit observed in MW-402-O1 is provided in Appendix E.

The sand and gravel deposits at the base of Landfill Area 1 are interpreted to be fluvially deposited river sand and gravel. These sand and gravel deposits thin towards the plant, corresponding to a thickening of the glacial till. Cooling water and firewater supply wells installed in the sand and gravel near the Penobscot River were initially capable of flows in excess of 1000 gallons per minute. Based on the limited size of the aquifer and the large volume of water these wells produced, the majority of their yield was probably the result of induced infiltration from Penobscot River water, indicating a good connection between groundwater and surface water in this area.

Marine Deposits

Two types of marine deposits were observed on the site. In the lower elevations of the plant and river areas, fine grained silt and clay deposits are observed near the ground surface. These are interpreted to be Presumpscot Formation: fine grained sediments carried by glacial streams and deposited in near shore marine environments. These deposits are primarily silt and clay sized particles, although they are composed primarily of rock flour, rather than clay minerals. The silt and clay deposits are observed in the top 10 feet of B-320-B1 and B-321-B1. This deposit was also observed in geoprobe borings advanced through leach field No.; 2, east of the plant laboratory/ changehouse building.

Another deposit of suspected marine origin is present on the bedrock ridge. Fine to medium well sorted sand is visible outcropping on the northeastern (upriver) side of the gully north of Landfill 4. This deposit strongly resembles beach sand and it is suspected that during emergence of coastal Maine, the fine grained marine sediments were winnowed by wave and wind action. This deposit is noted on boring logs for MW-408-O1 and MW-408-B1.

Anthropogenic Fill Material

The plant area was graded prior to construction. Fill material was used to replace soil of poor load bearing capacity. Based on boring logs and hand augured soil samples, the fill material within the plant area includes reworked sand and gravel, and till deposits. Fill was also placed as bedding for plant roads and railroads.

The five landfills also represent fill deposits. Mercury contaminated sludge was reportedly mixed with sand prior to or during its emplacement in the landfills to improve its load bearing capacity and to facilitate handling. Each of the landfills is capped. In addition to the Hypalon placed over Landfill Area 1 and Landfills 3, 4 and 5, each landfill is covered with soil.

An area north of Landfill 4 was formerly used as a sand and gravel borrow area. This area was refilled with material removed from the plant area during construction of the former sodium chlorate plant. Continuous soil samples were collected during advancement of the soil boring for monitoring well MW-407-B1, which is in the filled borrow area. The sample descriptions indicate that the fill material is approximately 17 feet thick. The arcuate shape of the gully indicates that the northeast, upriver side represents the extent of sand and gravel excavation and that the southwest, downriver, side of the gully represents the extent of the fill. Based on a ground surface elevation of approximately 82 feet and the lowest surface expression of the gully (an indentation in the 50 foot topographic contour), the maximum depth of the fill material here is anticipated to be approximately 30 feet.

The graded area below the paved sump, along the southern side of the northern stormwater outfall, also appears to comprise fill to a depth of approximately 2 feet. During the installation of soil lysimeters in this area, fragments of man-made materials, including approximately 10 graphite anodes, were observed.

Surface Soils

The Soil Conservation Service map of Penobscot County, Maine, sheet Number 256, indicates the presence of 14 soil types on the site. Examples of these descriptions range from "Adams loamy sand, 0 to 8 percent slopes (AaB)" to "Thorndike very stony silt loam, 15 to 35 percent slopes (TvD)". A copy of the SCS map and soil legend is provided in Appendix E.

The near surface soil at the site varies in composition among the ridge, plant, and river areas. The distribution of surface soil types has been further influenced by excavation, construction and filling. The following descriptions of soil distribution and soil profile have been compiled from observations made during soil sampling and soil borings during the SI, and from test pit logs of previous investigations. The soil profile observed in most test pits is generally consistent with the descriptions of soil stratigraphy developed from borings; however, observation of mottling and other indications of seasonally high groundwater levels are included.

Surface soil on the ridge is typified by an approximately 0.5 to 1.0 foot thick layer of loam with a high percentage of organic material (leaves, leaf mold, roots, etc.). On the ridge north of Landfill 5, mottling was observed at 2.5 feet below ground surface and water seeped into a pit (TP-103) at 3.5 feet below ground surface. The soil was described as till which became firm and platy at approximately 2 feet below ground surface. North of Landfill 3, till was observed close to the ground surface to the total depth of excavation at 3.8 feet (TP-106). In another excavation between Landfill 4 and the river (TP-107), the soils were described as fine sand and gravel. Mottling or other signs of seasonally high groundwater table were not observed.

The ground surface within the plant area is primarily paved. Where soil is exposed it is typically a sand fill of varying grain sizes. In the western portion of the plant, in the vicinity of the brine handling areas, it is capped with crushed stone. Test pits were excavated by previous consultants within the plant area, primarily to investigate soil types in the vicinity of proposed plant construction for the sodium chlorate plant and the warehouse building. Test pits in this area encountered a variety of materials, including silty gravelly sand, organic silt, peat, wood, clayey silt and fill. In general, the test pit logs indicate groundwater within approximately 3 feet of ground surface in the vicinity of the former sodium chlorate plant. Acheron advanced one test pit into the bedrock scarp. They encountered bedrock at one foot below ground surface at the top of the pit and 4.5 feet below ground surface at the bottom of the pit. They described the soil as till. Acheron also excavated a pit near the road and stormwater ditch in the low lying area east of the plant. The material encountered was a clayey silt/silty clay, consistent with the descriptions of the Presumpscot Formation. Water was observed at a depth of 2 feet, which corresponded to the depth to water in the adjacent stormwater ditch.

In the river area, the surface soil is typically dark brown gravelly sand with a thick vegetated layer of grasses. Closer to the plant area near B-316, the sand was observed to be finer grained and contained a little clay. The log of a test pit (TP-111) excavated by Acheron near B-316 indicates fill to a depth of 8 feet with a sharp contact between a one foot thick layer of blue-green silty clay and stratified sand and silt. Test pits advanced by CDM during the soil lysimeter investigation found fill to a depth of more than 2 feet -in the area below the paved sump. Groundwater in this area rose to approximately 8 inches below ground surface following the installation of the lysimeter.

The saturated hydraulic conductivities of the near surface soils are assumed to be similar to those tested with in-situ hydraulic conductivity (slug) tests in monitoring wells. By definition, the unsaturated hydraulic conductivities of these materials must be lower. An attempt to directly measure the unsaturated hydraulic conductivity at the site using a Guelph permeameter was unsuccessful.

Selected soil samples were collected from soil borings and analyzed for grain size distribution. The samples were selected to be representative of the various deposits observed at the site. A sample of the till which underlies much of the plant area was submitted from MW-404-B1. Two samples of the sandy soil were submitted from MW-405-B1, adjacent to the bedrock ridge near the former sodium chlorate plant. A sample of the till observed in the ridge area was submitted from MW-406-B1. Grain size curves and tabulations are presented in Appendix E.

The total organic carbon (TOC) content of selected site soils were measured by Acheron (Table 3-23, Appendix B). TOC ranged from 290 mg/kg to 3100 mg/kg, and averaged approximately 1000 mg/kg.

The storage capacity of site soils was evaluated by measuring the soil moisture at varying pressures and establishing a soil moisture retention curve. Two site soils were tested, including a well sorted (narrowly graded) medium sand from the ridge area, and till collected from MW-404-O1. These two soils are considered to represent the most and least permeable soils at the site and therefore the soils with the two extremes of soil moisture retention capacity. The calculations and curves are presented in Appendix E. The higher fines content of the till retained significantly more moisture than did the relatively clean sand deposit.

Infiltration was estimated based on a formula provided in Water Resources Inventory of Connecticut, USGS and Connecticut Water Resources Bulletin No. 28, 1978. The formula uses the percentage of surface area covered by glacial drift (sand and gravel) and empirical data shows good correlation with river systems throughout the northeast. Attempts to directly measure infiltration using a dual ring infiltrometer were unsuccessful due to the presence of gravel or due to leakage in sandy soils.

5.4 Site Hydrogeology

The hydrogeology of the site can be broadly divided into bedrock and overburden groundwater flow. In many locations on site, the till layer acts as an aquitard, maintaining the separation between these two water-bearing units. Stratigraphic cross sections were generated to illustrate site geology, extent and continuity of high permeability units, preferential pathways, and the relative thicknesses of saturated and unsaturated materials. The locations of cross sections were chosen to provide both cross-gradient and along-gradient expressions of subsurface soil conditions. In conjunction with the preceding descriptions of site geology, these cross sections help to form the conceptual hydrogeologic model. Cross sections can be found in the following figures:

Figure 5-4	Stratigraphic Cross Section Location Plan
Figure 5-5	Stratigraphic Cross Section A-A'
Figure 5-6	Stratigraphic Cross Section B-B'
Figure 5-7	Stratigraphic Cross Sections C-C' and D-D'
Figure 5-8	Stratigraphic Cross Section E-E'
Figure 5-9	Stratigraphic Cross Section F-F'

5.4.1 Bedrock

The phyllite bedrock observed at the site has very low primary porosity (typically 2-3 % or less). Therefore, the hydraulic properties are dominated by the degree and orientation of fractures. The highest hydraulic conductivities observed during the 1997 field season were found in MW-505-B1 (3.06E-2 cm/sec), MW-506-B1 (1.04 E-3 cm/sec), and MW-505-B2 (9.06 E-4 cm/sec). The highest conductivities observed during the 1994 Site Investigation were found in MW-401-B1 (1.36 E-3 cm/sec), MW-408-B1 (3.86 E-4 cm/sec), and MW-410-B1 (8.76 E-4 cm/sec).

Groundwater flow in bedrock will generally trend from areas of high to low hydraulic head. However, the actual flow pathways are determined by interconnected fractures capable of transmitting water. The specific path taken by groundwater may therefore be less direct than would be indicated by flow strictly perpendicular to groundwater contours. The majority of fractures observed in bedrock cores corresponded with bedding planes which have been mapped in outcrops as trending N86W to S16W and dipping 58 to 78 degrees north toward the Penobscot River. Additional fracture patterns were noted in outcrops and indicated by the VLF survey. These fracture sets are oriented north and northwest from the plant area toward the Penobscot River. The presence of fracture sets oriented toward the Penobscot River will likely serve to conduct groundwater flow to the river.

In addition to natural fractures, additional fracture sets may have been created during plant expansion to the edge of the bedrock scarp. When the railroad spur was constructed to serve the former sodium chlorate plant, blasting of bedrock was conducted in the vicinity of monitoring well P-2A. The extent of fractures induced by blasting is expected to be limited.

In general, most of the groundwater on the bedrock ridge flows from the highest points located northeast of Landfill 5 toward the low point of the ridge near Landfill 4 and northwest toward the Penobscot River. A lesser amount flows south toward the plant, where it discharges to overburden deposits or flows beneath the till to the Penobscot River.

5.4.2 Overburden

Groundwater flow in overburden deposits is controlled by the relative hydraulic conductivities of the sand and gravel deposits. Hydraulic conductivities measured in overburden deposits during the SI ranged through five orders of magnitude; from 3.93 E-7 (MW-508-O1) to 2.56E-1cm/sec (MW-405-01). The lowest hydraulic conductivities were measured in till deposits beneath the manufacturing plant. The highest hydraulic conductivities were measured adjacent to the bedrock scarp north of the former sodium chlorate plant (MW-405-O1) and in the sand and gravel deposits adjacent to the Penobscot River (MW-512-O1, MW-401-O1, MW-402-O1, and MW-513-O1).

Groundwater will seek preferential pathways through material with the highest hydraulic conductivity. The dense till material, where present, will limit groundwater flow. Till is observed overlying bedrock across portions of the ridge, beneath the plant area and beneath most of the area adjacent to the Penobscot River (see Figure 5-2). Where less dense, more granular material overlies glacial till, as is the case across most of the site, till will limit downward migration of groundwater and the predominant flow direction will be horizontal or along the top of the till surface toward the river. In some cases, fractures within the till may provide pathways for groundwater to migrate through this low permeability layer; in general, though, the till is expected to provide a surface for predominately lateral migration.

Granular fill or former stream channel beds will often form preferential flow pathways. Prior to the construction of the former sodium chlorate plant, the area adjacent to the bedrock scarp was wet and soil removal was conducted prior to the plant expansion into that area. This area was backfilled to support anticipated construction activities. The screened interval in MW-405-O1 may be in granular backfill related to construction of the former sodium chlorate plant. In general, however, hydraulic conductivities in wells located adjacent to the bedrock ridge were higher than elsewhere in the plant or river areas, with the exception of the very permeable sand and gravel deposits adjacent to the river (e.g. MW-512-O1).

5.4.3 Anthropogenic Features

In addition to naturally occurring preferential flow pathways, anthropogenic features may significantly influence groundwater flow. The plant is constructed above a thick sequence of dense till of low hydraulic conductivity. Based on drillers logs of borings advanced prior to plant construction, between two and ten feet of silty sand overlie the till in some locations. Subsurface utilities which are located below the water table may act as preferential flow pathways. Flow may also occur along the bedding or disturbed soil in utility trenches. The majority of the underground utilities within the plant are related to process water and the industrial sewer, and are installed below the frost line, approximately five feet below ground surface. Two abandoned water lines and an abandoned electrical conduit lead from the plant to the former river well pump houses. One of these water lines is an abandoned pipeline from the Hampden water supply which crosses beneath the Penobscot River. The approximate locations of underground utilities are indicated on Figure 2-3. Where applicable, underground utilities are also indicated on the stratigraphic cross sections (Figures 5-5 through 5-8).

The industrial sewer collects discharge from various buildings around the plant and flows through the neutralization tank prior to flowing to the NPDES discharge at the Penobscot River. The discharge pipe from the neutralization tank traverses in a straight line from the treatment wier to outfall 001 at the Penobscot River. The elevation of the industrial sewer ranges from Elevation 60.40 PD to Elevation 54.51 PD within the plant area. Stormwater is collected in two stormwater sewers which range in elevation from Elevation 56 PD to Elevation 49.56 PD.

Potentially the most significant anthropogenic feature affecting groundwater flow is the underdrain system constructed beneath the former sodium chlorate plant. The underdrains discharge to the first manhole of the western stormwater sewer located at the northwest corner of the former sodium chlorate plant. These underdrains flow constantly, even during extended periods of dry weather, suggesting that they receive discharge from groundwater in addition to surface water runoff. The invert elevation of the manhole near the former sodium chlorate plant is approximately Elevation 54 PD.

Groundwater is also occasionally collected and discharged from the basement of the office building. The basement of this building is approximately Elevation 60 PD. The building foundation had a perimeter drain which connected to a culvert leading to the southern drainage. During 1994 and 1995, seepage was observed through the foundation and in the spring of 1995 water flowed into the basement which required the use of a sump pump located in an electrical utility chamber. Plant personnel believe that the perimeter drain or its discharge line have become clogged.

5.4.4 Groundwater Flow

Groundwater contour maps for overburden and bedrock are provided as **Figures 5-10** and **5-11,** respectively. Synoptic groundwater level measurements for these maps were collected in December of 1997.

A groundwater divide is present approximately down the center of the bedrock ridge. The top of till or rock may locally affect the location of the divide in overburden. Specific fractures may locally alter the location of the groundwater divide in bedrock. Groundwater north of the divide flows directly to the Penobscot River. Groundwater south of the divide flows into the overburden deposits beneath the plant. Overburden groundwater will seek preferential pathways through deposits or anthropogenic features of relatively higher hydraulic conductivity.

Hydraulic conductivity values from available monitoring wells and descriptions from boring logs throughout the plant indicate that the soils adjacent to the bedrock scarp have higher hydraulic conductivities than those beneath the plant. These overburden deposits along the base of the landfill ridge are likely to form a preferential pathway for groundwater flow. Underdrains below the former sodium chlorate plant capture much of the groundwater between the bedrock ridge and the plant. This water is then discharged to the Penobscot River via the paved sump and the north ditch.

Varying degrees of groundwater seepage have been observed along the beach face adjacent to the Penobscot River. Areas of highest groundwater/beachface discharge appear to correspond to the alignment of abandoned Hampden water line which crosses the river, the water lines and electrical conduits leading from the plant to the pumphouse buildings and around the HoltraChem Outfall 001. These observations indicate that the utilities in this area of the site may represent preferential pathways for groundwater flow.

Shallow groundwater contours east of the plant are very close to the ground surface elevation. The stormwater ditch that extends from the railroad tracks west of Landfill 2 to just northeast of the transformer yard is approximately six feet deep. More water was observed flowing out of this ditch near the transformer yard than was flowing in where it crosses beneath the railroad tracks west of Landfill 2. Based on the shallow groundwater contours and the observed increased flow in the stormwater ditch, it appears that shallow groundwater is discharging to this ditch east of the plant.

The water table is also very close to the ground surface where the ditch passes between the HoltraChem and PERC plants. Based on the groundwater contours in this area and the wetland vegetation observed, this stormwater ditch also appears to be receiving recharge from groundwater.

Groundwater discharging along the southern side of the plant near the loading shed is collected in an eight-inch perforated subsurface drainage pipe installed for this purpose. The groundwater collection pipe was installed after water was observed flowing into the stormwater ditch from the bank.

Groundwater contours trend in a north-south direction as they pass the B-321, MW-505, and MW-511 clusters, indicating that the wells on the PERC property and the residences on Ferry Road are cross gradient from the HoltraChem site. Groundwater flow in this area is approximately perpendicular to and towards the Penobscot River, which is a regional discharge point for groundwater in the Orrington area. Monitoring well MW-511-B1 is artesian, with a static water level more than 3 feet above ground surface. A spring was noted on the bank of the southern cove at the base of the southerly stream. This spring is a discharge point for groundwater in this area.

Hydraulic Conductivities

Hydraulic conductivities were calculated for three general stratigraphic units: bedrock, till, and sand and gravel deposits. The geometric mean of the available hydraulic conductivity data from Acheron (Table 2-4, Appendix B) and slug tests performed for the SI (Table 3-3) were calculated for the three units. Calculations are provided in Appendix E.

Hydraulic conductivities in bedrock ranged from 7.1 E-7 cm/sec (2.0 E-3 ft/d) to 1.8 E-3 cm/sec (5.1 ft/d).

Hydraulic conductivities in till ranged from 1.8 E-6 cm/sec (5.1 E-3 ft/d) to 4.0 E-5 cm/sec (0.11 ft/d).

Hydraulic conductivities in sand and gravel deposits ranged from 4.6 E-4 cm/sec (1.3 ft/d) to 2.6 E-1 cm/sec (725 ft/day).

The hydraulic conductivity values for till deposits were generally more homogeneous than those for drift and bedrock deposits. Hydraulic conductivities obtained from wells screened in the till were all within one order of magnitude, while values for the bedrock and overburden deposits varied by as much as three orders of magnitude.

Horizontal Hydraulic Gradients

Horizontal hydraulic gradients on the site are controlled by the surface, till surface and bedrock topography, and the horizontal hydraulic conductivities of site media. In general, lower conductivity materials are able to support steeper hydraulic gradients; water elevations in higher conductivity materials are more easily equilibrated by flow through these media.

Water elevations in bedrock are 60 to 70 feet above the river level within 200 feet of its bank, a horizontal hydraulic gradient of 0.30. This large hydraulic gradient suggests that the low hydraulic conductivity of the bedrock limits groundwater flow to the Penobscot River.

A similar steep hydraulic gradient (approximately 0.27) is observed from the plant area to the Penobscot River. In this area, a relatively thin veneer of sand and gravel deposits is underlain by steeply dipping glacial till, which acts as an aquitard limiting the downward percolation of groundwater. The apparently steep hydraulic gradient in this region is indicative of groundwater flow along the surface of the till. Although flow in this area largely occurs in sand and gravel deposits, the volumetric flow rates from the plant to the river are not as high as this gradient would imply, due to a shallow saturated thickness of overburden deposits.

Sand deposits adjacent to the bedrock scarp along the northern edge of the plant support a very small (0.002) hydraulic gradient. These sand deposits have hydraulic conductivities two to three orders of magnitude greater than the till deposits or bedrock. The higher hydraulic conductivity of this deposit facilitates the equilibration of hydraulic heads.

Hydraulic gradients between Landfill Area 1 and the river are strongly influenced by tidal variations in the river. The response of the aquifer to the tides, however, is nonlinear and involves a significant time lag, because water can enter the aquifer vertically during the flooding tide, but must seep horizontally out from the beach during low tide (Turner et al., 1996). The net response of the water levels in the Landfill Area 1 wells, then, is a time-dependent hydraulic gradient. During low tide, a large hydraulic gradient is present from the landfill to the river, but this gradient is significantly reduced by the development of a seepage face along the shoreline. During high tide, the gradient reverses, pushing water back toward the plant from the river. The time-dependent hydraulic gradient was modeled using the sloping beach face solution to the Boussinesq equation (Nielsen, 1990; Turner et al., 1996). The analytical solution, based on the physical characteristics of the beachface and the observed tidal variations in five wells below Landfill Area 1, indicated an average seepage face elevation of 1.865 ft NGVD, during a maximum tidal range of 14 feet. Tidal cycle monitoring and modeling of the water table super-elevation relative to the river indicate that the time-averaged gradient below Landfill Area 1 ranges from 0.001 to 0.005.

Seepage Velocities

Seepage velocities were calculated for areas of the site where significant discharge to the river occurs. The seepage velocity, also known as the mean linear velocity, was calculated from the hydraulic conductivity, the hydraulic gradient, and an assumed effective porosity. For flow below Landfill Area 1, seepage velocities were calculated from gradients and conductivities where applicable, and from flux estimates and saturated cross sectional areas for methods where gradients were not calculated. Calculated seepage velocities provide an estimate of how quickly groundwater moves in various deposits. The assumed effective porosities were 25% for sand and gravel, 5% for till, and 2.5% for bedrock. The assumed saturated cross sectional area below Landfill Area 1 was 6,750 ft.^2 (see Appendix E).

The calculated seepage velocities were as follows:

- For flow in bedrock from the bedrock ridge to the Penobscot River, 5 ft/day, or 1800 ft/yr.
- For flow in overburden sand and gravel along the bedrock scarp, 0.10 ft/day, 36.5 ft/yr.
- For flow in overburden sand and gravel below Landfill Area 1,0.24 to 0.42 ft/day, or 86 to 155 ft/yr.

These seepage velocity calculations should be considered estimates as our evaluation of porosity for materials on the site is limited to measurements on similar deposits at other sites. Differences in porosity can lead to significant overestimates or underestimates of seepage velocities. For example, if the estimate of porosity for any of the materials were halved, (e.g. bedrock porosity equals 1.25% vs. 2.5%) seepage velocities for that deposit would be doubled. Nonetheless, the calculated seepage velocities above provide at least an order of magnitude approximation of how quickly groundwater is migrating through site media. Seepage velocity calculations are provided in Appendix E.

Vertical Hydraulic Gradients

Vertical hydraulic gradients were calculated from data collected at monitoring well clusters. A summary of the vertical hydraulic gradients was provided in Table 3-4.

The observed general trends in vertical hydraulic gradients are divided into regions. Upward hydraulic gradients were observed along the river and in the eastern half of the plant area. Downward gradients were observed along the bedrock ridge, where thin overburden deposits are discharging to underlying bedrock, and along the western edge of the plant area, where overburden deposits are underlain by steeply dipping glacial till.

A strong upward gradient within the bedrock is observed in monitoring well clusters B-303 on the bedrock ridge and in the B-321, MW-505, and MW-511 clusters on the PERC property south of the plant. These clusters with multiple screens in bedrock indicate that regional bedrock groundwater flow is discharging to the Penobscot River. Upward gradients are also apparent between bedrock and overburden in the vicinity of the Penobscot River below the plant. On the bedrock ridge, a downward gradient is typically observed between the overburden and the bedrock wells in locations where the overburden is saturated.

Three well clusters are located adjacent to the bedrock scarp in the vicinity of the plant. A fourth well cluster is located along the bedrock scarp adjacent to the Penobscot River. An upward gradient is present at the MW-405 cluster. There is almost no vertical gradient present at the B-315 cluster. A downward vertical gradient is present at the MW-403 cluster, and an upward vertical gradient is present at the MW-401 cluster. This pattern indicates that groundwater from the bedrock ridge is discharging to overburden deposits adjacent to the scarp upgradient of cluster B-315.

An area of downward hydraulic gradients is present across the center of the site, from north of the lined process lagoon to the HoltraChem/PERC property line near MW-504. Downward hydraulic gradients were observed for clusters MW-403, MW-503, B-316, and MW-504.

Due to differing tidal efficiencies and delay times, simultaneous multiple well water level monitoring was required to evaluate the net vertical hydraulic gradients in tidally influenced well clusters adjacent to the Penobscot River. These net gradients are summarized in Table 3-6. In general, an upward gradient was observed between the bedrock and the deepest overburden screen. A downward gradient was typically observed between the shallowest and the next deepest overburden screened interval. These converging vertical gradients indicate discharge is occurring to the Penobscot River most readily through the intermediate depth interval, which corresponds to the high conductivity sand and gravel deposits.

Infiltration

The amount of water recharging groundwater aquifers is governed by precipitation, surface runoff, evaporation and transpiration (evapotranspiration), and by characteristics of the surface such as slope, vegetation and the infiltration capacity of surficial deposits. Till, clay, or pavement at the ground surface will limit infiltration. Conversely, sand and gravel permit rapid infiltration. Steep slopes, such as the bedrock scarp and the slopes from the ridge to the Penobscot River, typically have high surface water runoff and low infiltration. The landfill caps may have differing impacts based on their specific design and construction. Landfill 4 has a 2.5-foot thick clay cover over a granular drainage layer and a Hypalon membrane. The water which runs off of Landfill 4 to the north will most likely infiltrate the surficial sand deposits present there. The presence of landfills and other man-made surfaces were addressed through conservative assumptions of infiltration rates.

Infiltration was calculated for three types of surficial deposits: till, sand and gravel, and pavement. Estimates of recharge and runoff were made considering the percentage of the surface area covered with sand and gravel. Although little water is expected to penetrate pavement, a value one half the infiltration expected for drift was used to account for potential infiltration through small unpaved areas and cracks.

Based on the extent of till, sand and gravel or fill as shown on Figures 5-2 and 5-3, surficial material types were assigned to recharge areas to calculate a water balance.

5.4.5 Water Balance

The water balance was calculated in two ways. First, the hydraulic gradients and hydraulic conductivities measured at the site were used to estimate the amount of groundwater discharging to the Penobscot River. Second, the volume of water recharging the groundwater at the site was calculated based on the infiltration assumptions described above.

The regional and site specific groundwater flow to the river was calculated using the hydraulic gradient between the plant and the river and an average (geometric mean) of the bedrock and till hydraulic conductivities. The individual geometric means for bedrock and till hydraulic conductivities were generally similar and the bedrock and till can be considered to act as one relatively low permeability unit. For fractured rock, an aquifer is often considered to be 500 feet thick with the hydraulic conductivity decreasing with depth. To account for the decreasing hydraulic conductivity with depth and the fact that all our measurements were of the upper portion of rock, an aquifer thickness of 300 feet was used. The length of shoreline from downgradient of Landfill 1 to the B-320 cluster was assumed to be the area of discharge. The quantity of groundwater estimated to be discharging to the Penobscot River by this method was 35 gpm.

For the aquifer recharge calculation, groundwater was assumed to discharge to the Penobscot River through two main routes: from the ridge north to the river, and from the ridge, the valley and the plant to the river. The areas where recharge would contribute to groundwater flowing through these areas was digitized and the amount of infiltration was estimated based on its assigned surface type. The amount of water estimated to be discharging to the Penobscot River by this method was 37 gpm.

The close agreement of the numbers generated by these two different approaches provides some confidence that the assumptions used for factors such as hydraulic conductivity, infiltration and recharge areas are reasonable. However, a water balance is only an estimate and there are many assumptions included which introduce uncertainties. For instance, an average hydraulic conductivity was used which may be lower than the actual hydraulic conductivity of localized deposits. An assumption was made of the extent of the area contributing to recharge of groundwater. Because the Penobscot River is a regional groundwater discharge point, the area of contribution to groundwater flow could be significantly greater than the area assumed for the water balance calculation. This would result in more groundwater passing beneath the site and discharging to the river than was estimated. However, as this water infiltrated in the upper reaches of the watershed it would be expected to pass below water which infiltrated closer to the site. This deeper water is referred to as underflow. Because underflow would most likely pass beneath the site in bedrock (below till) it is not expected to come in contact with contamination and, therefore, does not impact contaminant flux from the site.

Water balance calculations for this investigation were performed to estimate the flux of contaminated groundwater off site. Because the highest concentrations of mercury and chloropicrin observed in groundwater are primarily in the wells below Landfill Area 1, additional calculations quantifying the groundwater flux off site in this region were performed. The water flow through this area was estimated using four different methods.

The first two methods used assumed infiltration or a combination of hydraulic gradients, conductivities and infiltration to estimate the amount of water which would discharge from the plant area beneath Landfill Area 1 to the Penobscot River. The second two methods used hydraulic gradients modeled for or measured in the sand and gravel deposits at the base of Landfill Area 1. Each of these methods contain assumptions with associated uncertainties. The four methods were performed to evaluate the range of groundwater fluxes, identify similar results in the predicted fluxes with the various approaches, and to provide for evaluation of the ranges and degree of uncertainty in the estimates. A description of the various methods for estimating groundwater flow from the base of Landfill Area 1 follows.

The first method estimated the volume of water recharging the area which discharges between the bedrock scarp and the north ditch based on the infiltration assumptions described in Section 5.4.4. The volume of water available for groundwater recharge was computed based on estimated evapotranspiration rates at varying times throughout the year. A percentage of available water was then assumed to infiltrate to groundwater based on an empirical relationship between observed infiltration and percentage of stratified drift in surficial materials (USGS, 1979). Establishment of a recharge area for the river area was complex. An area of infiltration was established which began on the southern side of the ridge and included the plant and the area between the plant and the river. Because of cracks in the pavement and the lack of evapotranspiration from plants, the paved plant area (from the salt storage pad to the office) was conservatively assumed to have one half the infiltration rate of sand and gravel (stratified drift). The area from the plant to the Penobscot River was assumed to be sand and gravel. Water percolating through the areas of infiltration described above was assumed to pass through and be contaminated with the concentrations detected in the wells adjacent to the river.

The theoretical recharge area extends at least to the nearest surface water divide to the east. The shallow groundwater flowing toward the plant from the east is expected to discharge to the southern drainage ditch and its tributaries. However, some groundwater, at greater depths, will likely flow through the overburden and bedrock deposits beneath the plant. Groundwater at depth is not expected to become contaminated except where it passes through the areas of high chloropicrin and mercury concentrations. To account for underflow which will pass through contaminated areas, the volume of groundwater seeping through the till at the western side of the plant (near MW-404-O1 and P-7) was calculated. This portion of the calculated underflow was added to the volume calculated to pass through contaminated zones.

The volume of water calculated to infiltrate the plant and the south half of the bedrock ridge (which discharges to the plant) was approximately 1020 ft^3/day or the equivalent of 5.3 gpm. However, during the course of the SI, groundwater was observed to be discharging to the underdrains at the former sodium chlorate plant and potentially along the storm sewer leading from the underdrains to the paved sump. Flows at the paved sump were measured during periods of no observed overland flow at rates ranging from 2.19 gpm in August to 21.7 gpm in April. Water which infiltrates the plant but is discharged at the paved sump is not available for flow beneath Landfill Area 1 where the greatest levels of contamination in groundwater have been documented. Conservatively assuming a base flow in underdrains and underground utilities of approximately 3 gpm, the remaining flux of groundwater available to discharge beneath Landfill Area 1 was estimated to be 2.3 gpm. Limited infiltration through the Landfill Area 1 cap, and discharge from the till layer, were then added to this flux to estimate a discharge below the landfill.

In the second method, the cross sectional area of the stratified drift and the hydraulic gradients and hydraulic conductivities measured at the site were used to estimate the groundwater flux above Landfill Area 1. The hydraulic gradients between monitoring wells B-315-O1 and MW-403-O1, located along the bedrock scarp where the stratified drift deposits are thickest, were used to calculate the flux of groundwater from the site toward Landfill Area 1. Using a cross sectional area of approximately 6000 ft^2 and an average hydraulic conductivity of 1.8 E-3 cm/sec (5.1 ft/day) yields an estimate of 0.8 gpm. Because the hydraulic gradients measured in the plant are reflective of any influence the underdrains may have, it is not necessary or appropriate to subtract the flow of water observed at the paved sump during dry conditions. Infiltration through the landfill cap and discharge from the till were added to the estimated flux above the landfill to estimate the total discharge of water to the river.

These two methods provide a range of volume estimates for groundwater moving from the plant area to the river area. The contributions from seepage through the underlying till (underflow) and infiltration in the area between the plant and the river are estimated at 0.12 gpm and 1.14 gpm, respectively. Therefore, the estimated discharge of groundwater along the base of Landfill Area 1 ranges from 2.1 gpm (397 ft^3/day) to 3.6 gpm (685 ft^3/day). [see Appendix E]

Two additional methods of estimating groundwater flux from the base of Landfill Area 1 were performed which utilize the net hydraulic gradients and hydraulic conductivities of the sand and gravel deposits adjacent to the river. As discussed in Section 5.4.4, water level and horizontal hydraulic gradients in this area are strongly influenced by the large tides (12.8 foot mean) in the Penobscot River. Measurement of average water levels and net hydraulic gradients in the aquifer required monitoring of water levels throughout the tidal cycles. In the first of the hydraulic gradient methods, the elevation of the water table just inland of the river bank (beach) was modeled using equations presented in Turner, et. al., 1996. The groundwater flux estimated through this method was 5.1 gpm. However, due to the observed development of a seepage face which the authors acknowledged was not adequately addressed by the available calculations, and the sensitivity of the flux calculations to minor changes in hydraulic gradients, the model gradients were considered potentially inaccurate, and therefore required site specific verification.

To provide for direct measurement of hydraulic gradients between monitoring wells at the base of Landfill Area 1 and the Penobscot River, two piezometers were installed at the top of the river bank and water levels were again collected over the entire tidal cycle. The piezometers were surveyed when installed and again after data inconsistencies (negative gradients indicating flow form the river toward the plant) were observed. Groundwater flux estimates generated from the well and piezometer data range from 3.6 to 7.1 gpm. It is important to note that due to the high hydraulic conductivities at the base of Landfill Area 1, differences in water level measurement and survey elevations of less than one tenth of a foot can change calculated flux estimates by a factor of 2. Therefore, the groundwater flux estimates from the modeled and monitored gradient approaches should be compared to and used with the fluxes estimated from the other two methods. This comparison indicates a minimum predicted flux of 2.1 gpm, a maximum of 7.1 gpm, and a mean of 4.8 gpm.

5.5 References

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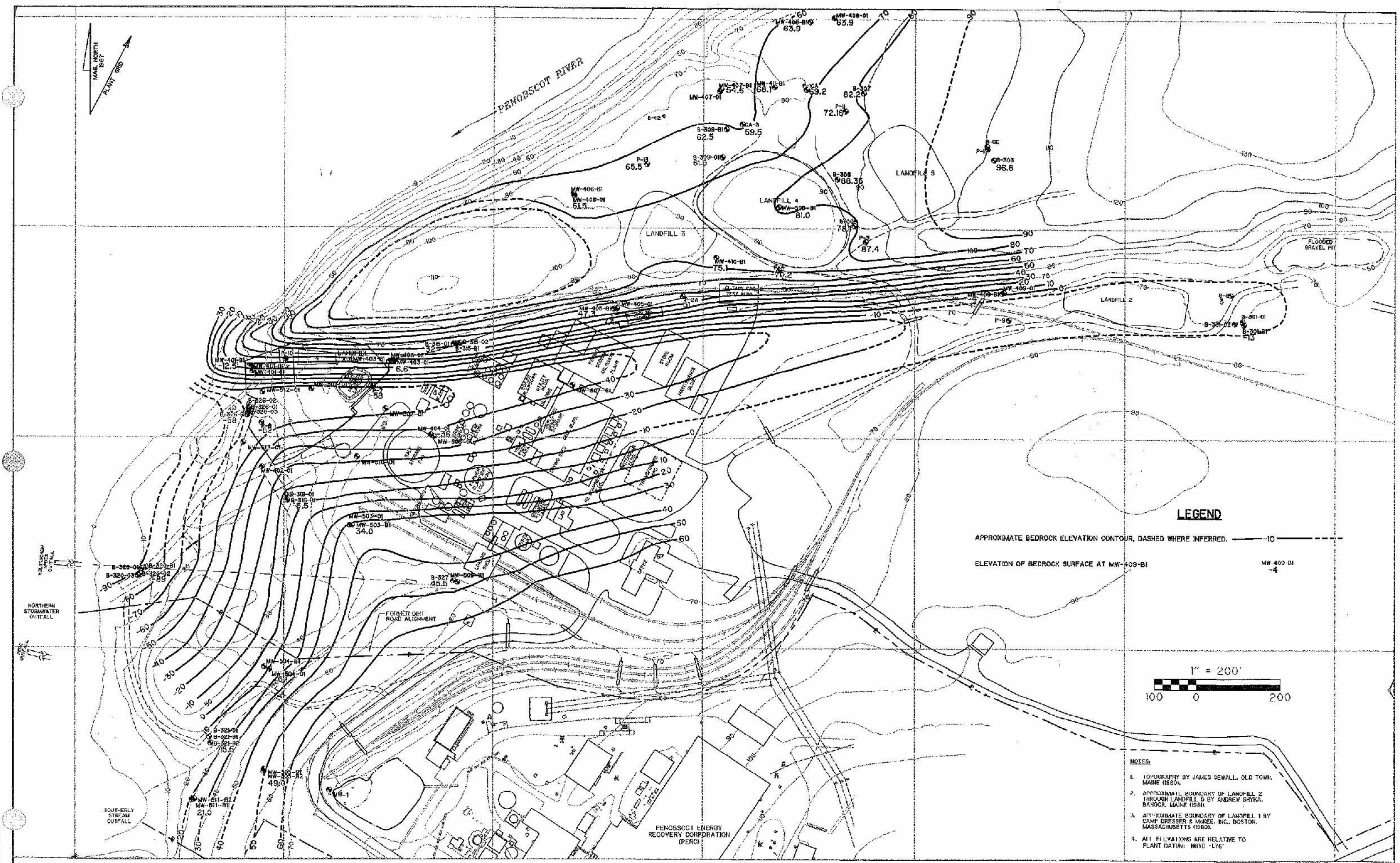

LEGEND

APPROXIMATE BEDROCK ELEVATION CONTOUR, DASHED WHERE INFERRED. —— -10 —— – – –

ELEVATION OF BEDROCK SURFACE AT MW-409-BI   MW-409-BI -4

1" = 200'

100 0 200

NOTES:

1. TOPOGRAPHY BY JAMES SEWALL, OLD TOWN, MAINE (1980).
2. APPROXIMATE BOUNDARY OF LANDFILL 2 THROUGH LANDFILL 5 BY ANDREW SHYKA, BANGOR, MAINE (1981).
3. APPROXIMATE BOUNDARY OF LANDFILL 1 BY CAMP DRESSER & McKEE, INC., BOSTON, MASSACHUSETTS (1980).
4. ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM: NGVD -L76'

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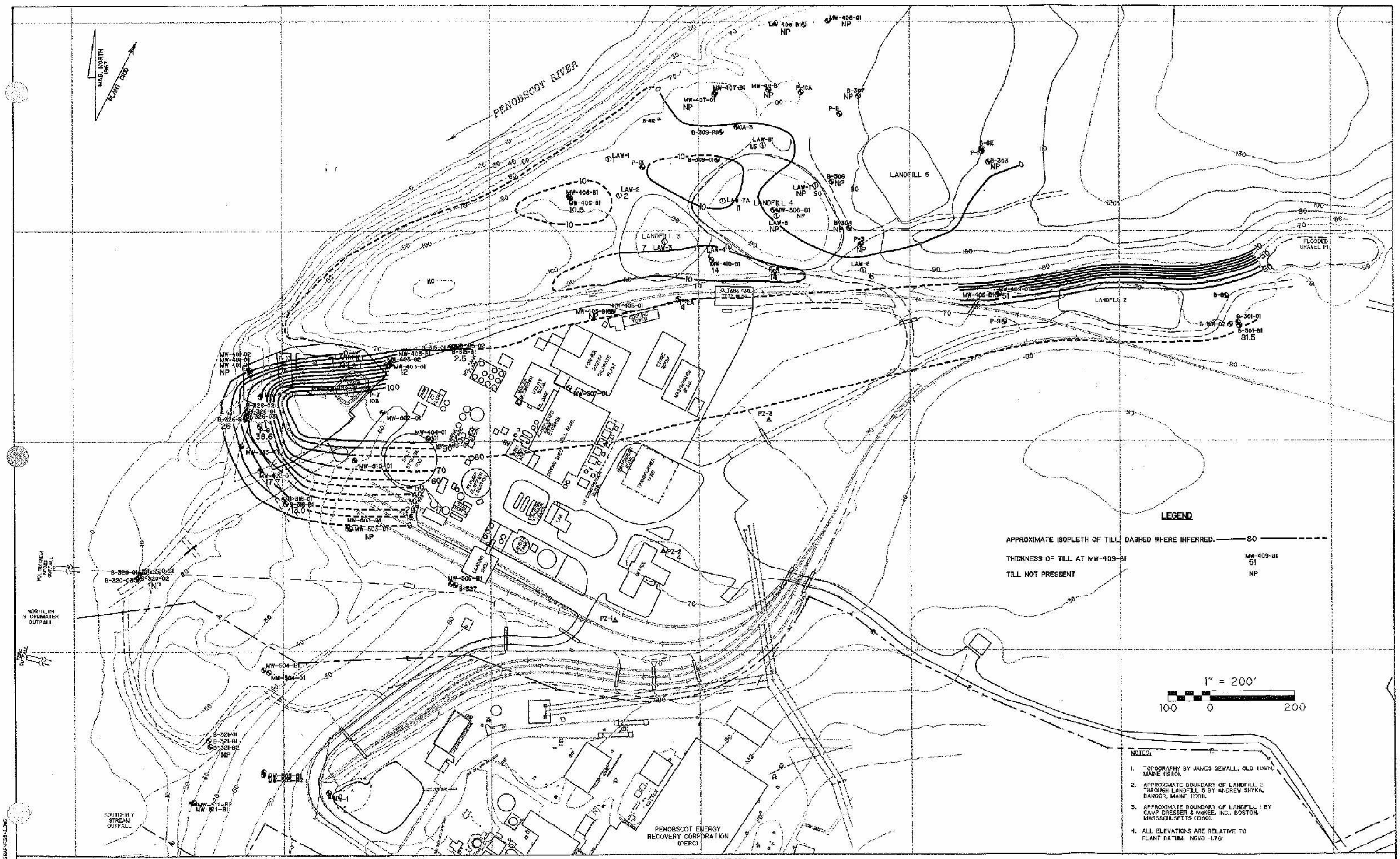
BEDROCK TOPOGRAPHIC SURFACE

Figure No. 5-1



LEGEND

APPROXIMATE ISOPLETH OF TILL, DASHED WHERE INFERRED. —— 80 —— — —

THICKNESS OF TILL AT MW-409-B1 — MW-409-B1 51

TILL NOT PRESSENT — NP

1" = 200'

100 0 200

NOTES:

1. TOPOGRAPHY BY JAMES SEWALL, OLD TOWN, MAINE (1980).
2. APPROXIMATE BOUNDARY OF LANDFILL 2 THROUGH LANDFILL 5 BY ANDREW SHYKA, BANGOR, MAINE (1981).
3. APPROXIMATE BOUNDARY OF LANDFILL 1 BY CAMP DRESSER & McKEE, INC., BOSTON, MASSACHUSETTS (1980).
4. ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM: NGVD -1.76'

Q:\0654\10508\GRAP\FIG5-2.DWG

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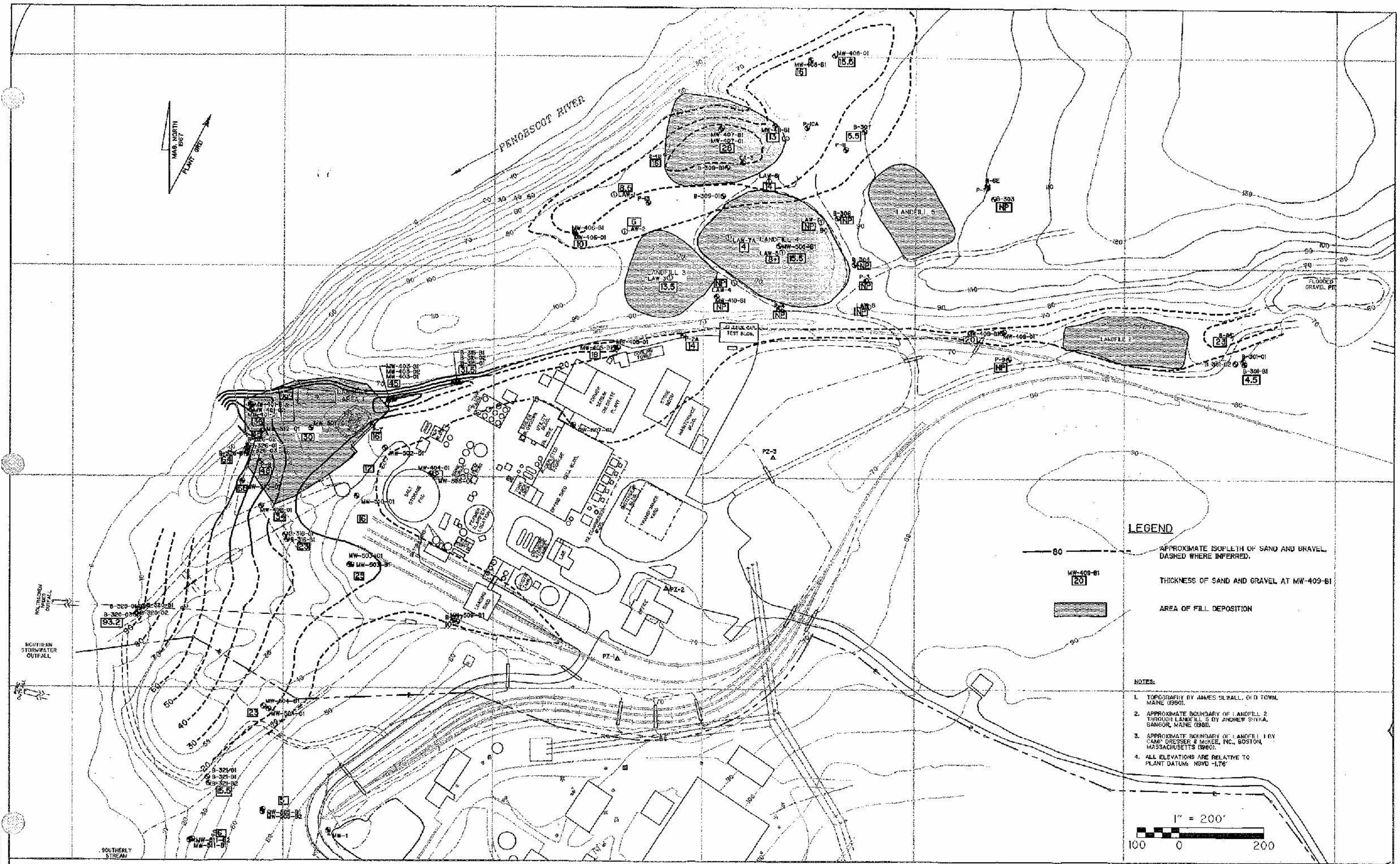
EXTENT AND THICKNESS OF GLACIAL TILL

Figure No. 5-2



LEGEND

—— 80 —— — —	APPROXIMATE ISOPLETH OF SAND AND GRAVEL, DASHED WHERE INFERRED.
MW-409-B1 20	THICKNESS OF SAND AND GRAVEL AT MW-409-B1
▨	AREA OF FILL DEPOSITION

NOTES:

1. TOPOGRAPHY BY JAMES SEWALL, OLD TOWN, MAINE (1980).
2. APPROXIMATE BOUNDARY OF LANDFILL 2 THROUGH LANDFILL 5 BY ANDREW SHYKA, BANGOR, MAINE (1981).
3. APPROXIMATE BOUNDARY OF LANDFILL 1 BY CAMP DRESSER & McKEE, INC., BOSTON, MASSACHUSETTS (1980).
4. ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM: NGVD -1.76'

1" = 200'

100 0 200

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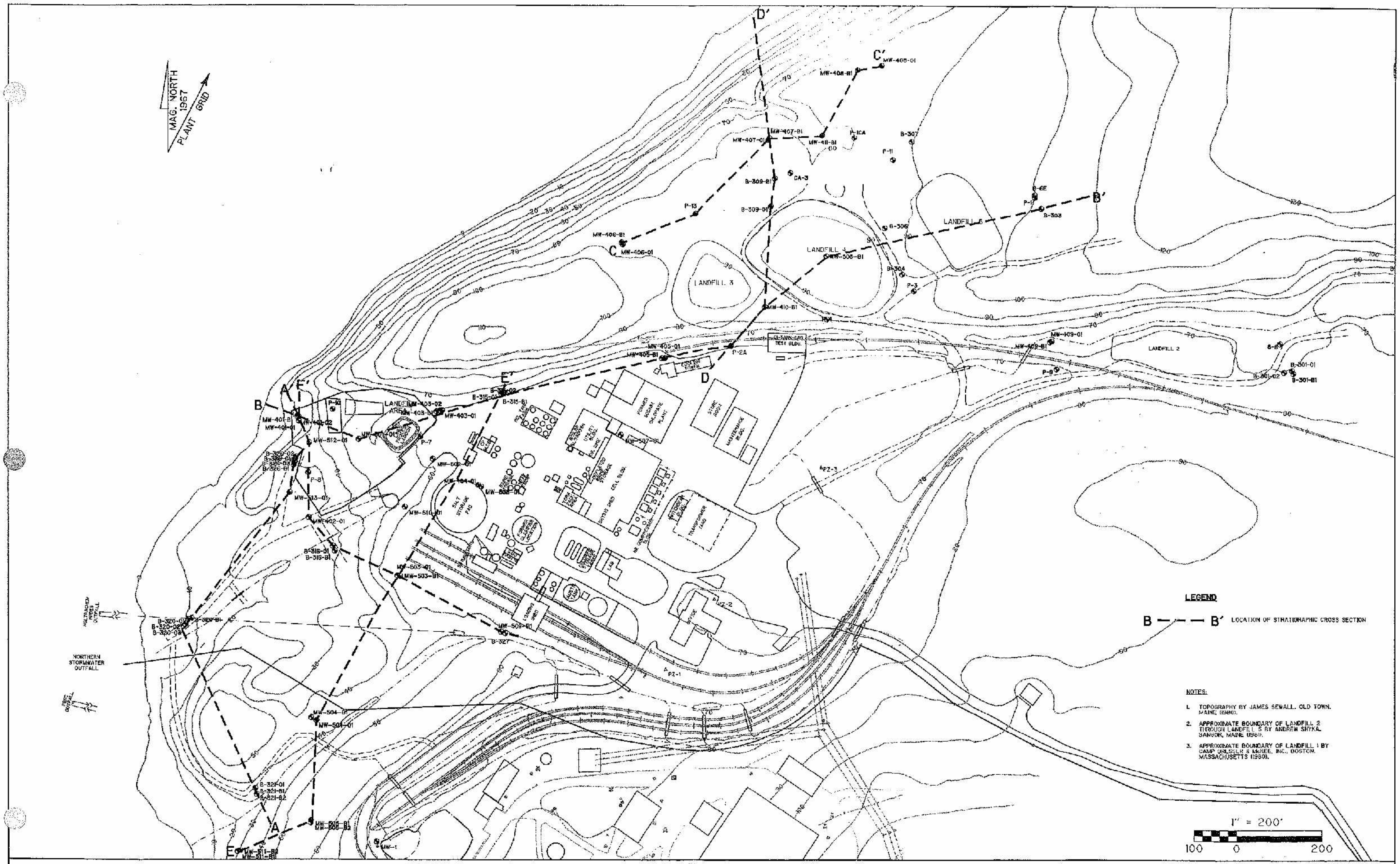
EXTENT AND THICKNESS OF SAND AND GRAVEL, AND FILL

Figure No. 5-3



LEGEND

B — — — B′ LOCATION OF STRATIGRAPHIC CROSS SECTION

NOTES:

1. TOPOGRAPHY BY JAMES SEWALL, OLD TOWN, MAINE (1980).
2. APPROXIMATE BOUNDARY OF LANDFILL 2 THROUGH LANDFILL 5 BY ANDREW SHYKA, BANGOR, MAINE (1981).
3. APPROXIMATE BOUNDARY OF LANDFILL 1 BY CAMP DRESSER & McKEE, INC., BOSTON, MASSACHUSETTS (1980).

1″ = 200′

100 0 200

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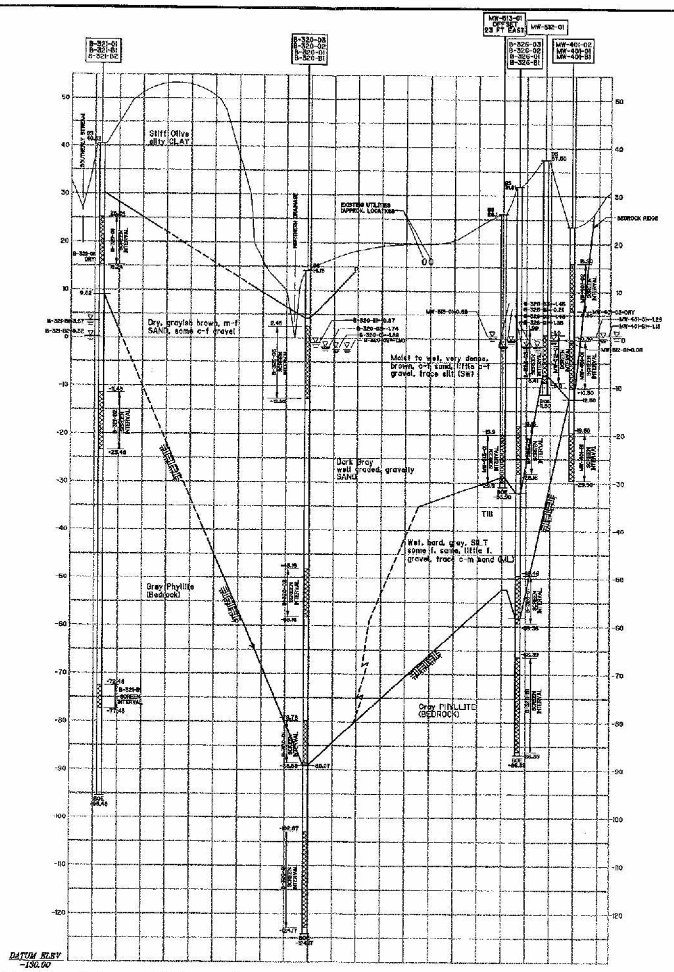
STRATIGRAPHIC CROSS SECTION LOCATION PLAN

Figure No. 5-4



SECTION A - A′

SCALE:
HORIZONTAL - 1" = 200′
VERTICAL - 1" = 20′

NOTE:

ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM-NGVD -1.76.

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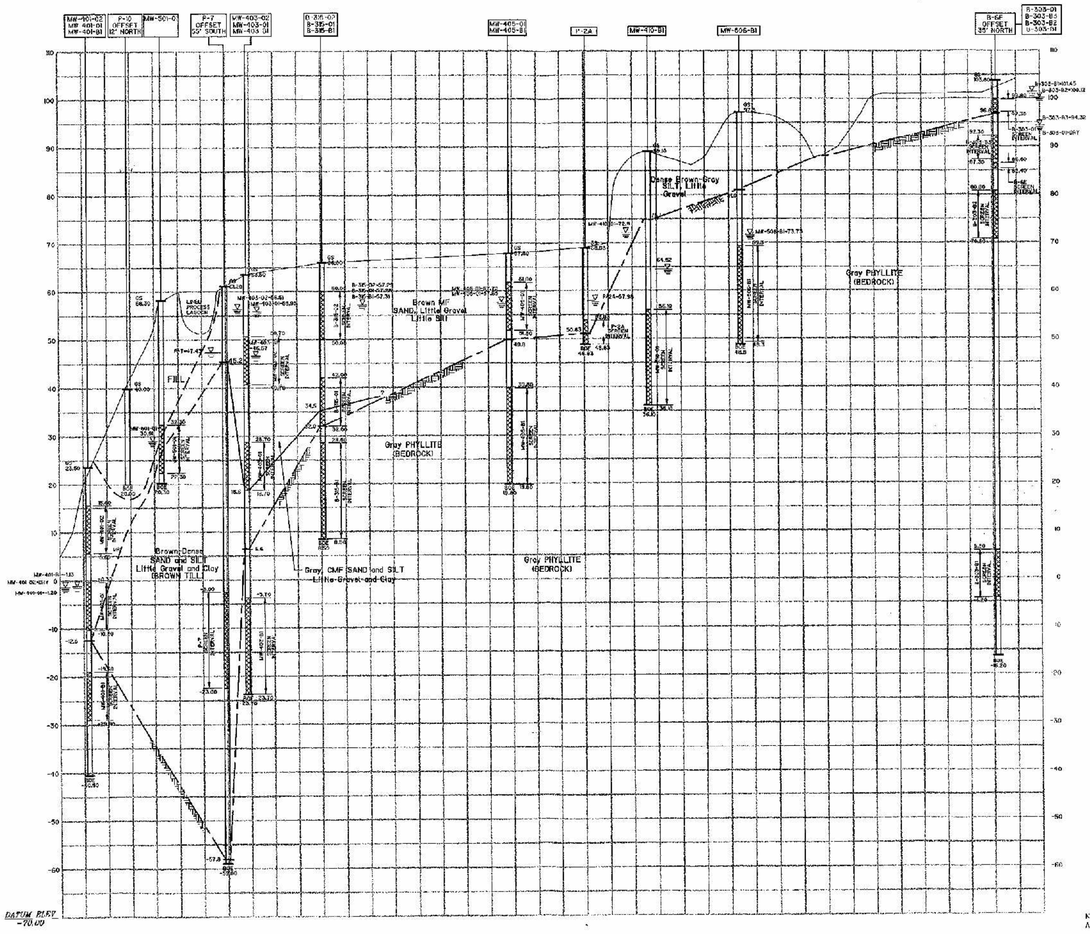
STRATIGRAPHIC CROSS SECTION A-A′

Figure No. 5-5



SECTION B - B'

SCALE:
HORIZONTAL = 1" = 200'
VERTICAL = 1" = 20'

NOTE:
ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM = NGVD -1.76'

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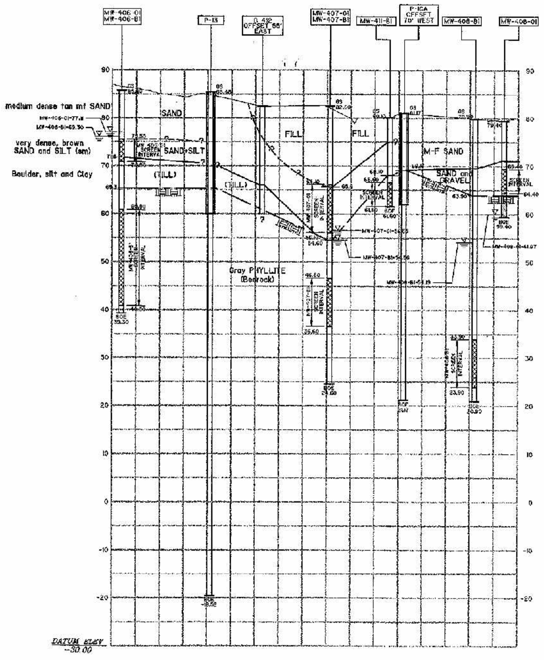
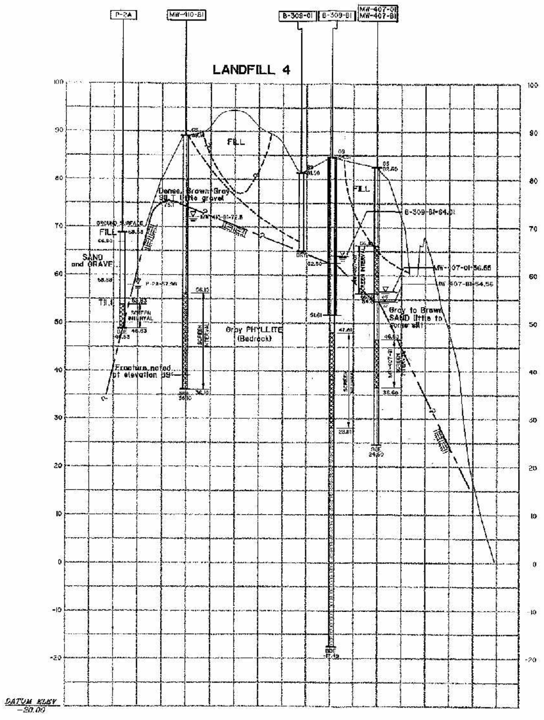
STRATIGRAPHIC CROSS SECTION B-B'

Figure No. 5-6



SECTION C - C'

SCALE:
HORIZONTAL - 1" = 200'
VERTICAL - 1" = 20'



SECTION D - D'

SCALE:
HORIZONTAL - 1" = 200'
VERTICAL - 1" = 20'

NOTE:
WATER LEVEL ELEVATIONS AS OF 12/97

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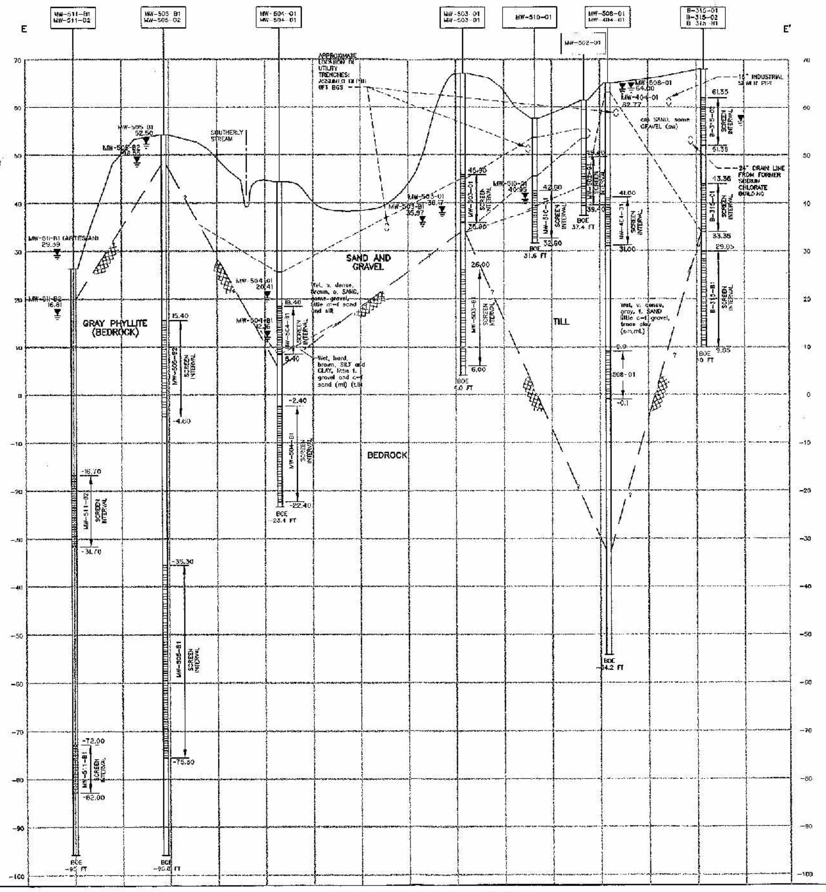
STRATIGRAPHIC CROSS SECTIONS C-C' AND D-D'

Figure No. 5-7



NOTE:

1. ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM=NGVD -1.76.
2. WATER LEVELS MEASURED IN DECEMBER 1997.

SECTION E-E'

SCALE:
HORIZONTAL - 1" = 100'
VERTICAL - 1" = 10'

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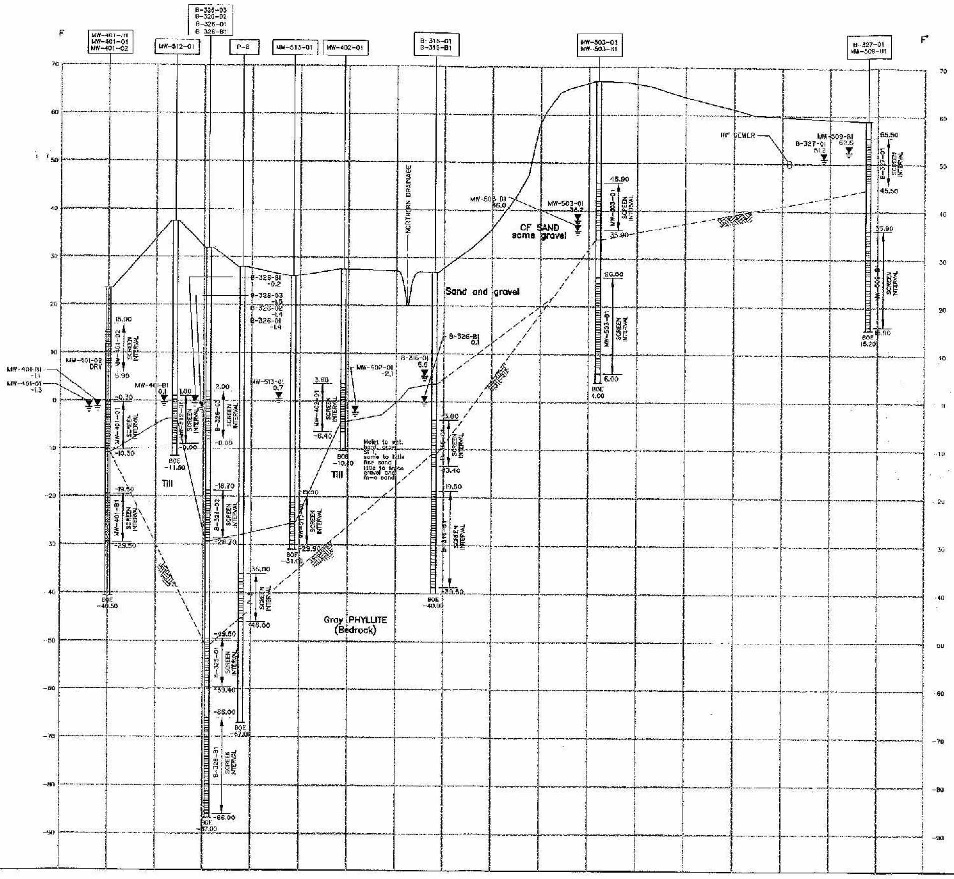
STRATIGRAPHIC CROSS SECTION E-E'

Figure No. 5-8



NOTE:

1. ALL ELEVATIONS ARE RELATIVE TO PLANT DATUM=NGVD -1.76.
2. WATER LEVELS MEASURED IN DECEMBER 1997.

SECTION F-F'

SCALE:
HORIZONTAL - 1" = 100'
VERTICAL - 1" = 10'

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STRATIGRAPHIC CROSS SECTION F-F'

Figure No. 5-9

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