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VOLUME I
HYDROGEOLOGIC STUDY
SANCO LANDFILL EXPANSION
BETHLEHEM, NEW HAMPSHIRE

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VOLUME I

TABLE OF CONTENTS

	Page
1.00 INTRODUCTION	1
1.10 OBJECTIVE AND SCOPE OF STUDY	1
1.20 SCOPE OF WORK	2
1.30 SITE DESCRIPTION	2
1.40 PROJECT DESCRIPTION	3
2.00 PREVIOUS STUDIES	4
3.00 CURRENT EXPLORATIONS	5
3.10 SEISMIC REFRACTION SURVEY	5
3.20 TEST BORINGS	5
3.30 BEDROCK PROBES	6
3.40 PIEZOMETER INSTALLATIONS	7
3.50 MONITORING WELL INSTALLATIONS	8
3.60 BOREHOLE HYDRAULIC CONDUCTIVITY TESTING	8
4.00 LABORATORY TESTING PROGRAM	9
5.00 SITE GEOLOGY	9
5.10 GEOLOGIC SETTING	9
5.20 GEOLOGIC MATERIALS	11
5.21 Bedrock and Bedrock Topography	11
5.22 Lower Glacial Till	12
5.23 Ice-Contact Stratified Drift	13
5.23.1 Silts	13
5.23.2 Gravelly Sands	14
5.24 Upper Glacial Till	14

TABLE OF CONTENTS (continued)

6.00	SITE HYDROLOGY	15
6.10	SURFACE WATER HYDROLOGY	15
6.20	GROUNDWATER HYDROLOGY	15
6.21	Hydraulic Characteristics of Subsurface Materials	15
6.22	Groundwater Levels and Flow Directions	17
6.23	Hydraulic Gradients and Seepage Velocities	19
6.24	Groundwater and Surface Water Quality	21
6.30	SUMMARY OF HYDROGEOLOGIC FINDINGS	23
6.40	LANDFILL DEVELOPMENT HYDROGEOLOGIC CONSIDERATIONS	24
6.41	Landfill Base Level	24
6.42	Landfill Base Subgrade Characteristics	25
6.43	Summary	25
7.00	GROUNDWATER QUALITY MONITORING	26
7.10	SAMPLING LOCATIONS	27
7.20	MONITORING WELL INSTALLATION PROCEDURES	27
7.30	SAMPLING PROCEDURES	28
7.40	SCOPE OF ANALYTICAL TESTING	28
7.50	POST-CLOSURE GROUNDWATER MONITORING	29

TABLES

TABLE 1 - SUMMARY OF GROUNDWATER LEVEL OBSERVATIONS

TABLE 2 - SUMMARY OF TOTAL VOLATILE ORGANIC COMPOUNDS IN SURFACE WATER AND GROUNDWATER

TABLE 3 - SUMMARY OF HYDRAULIC CONDUCTIVITY CALCULATIONS

TABLE OF CONTENTS (continued)

FIGURES

FIGURE 1 - LOCUS PLAN

FIGURE 2 - SITE PLAN

FIGURE 3 - EXPLORATION LOCATION PLAN

FIGURE 4 - SUBSURFACE PROFILES

FIGURE 5 - SUBSURFACE PROFILES

FIGURE 6 - SUBSURFACE PROFILES

FIGURE 7 - WATERSHED BOUNDARY

FIGURE 8 - GROUNDWATER ELEVATION CONTOUR - UPPER WELLS

FIGURE 9 - GROUNDWATER ELEVATION CONTOUR - LOWER WELLS

FIGURE 10 - VERTICAL FLOW NET CHARACTERIZATION, SECTION I-I'

FIGURE 11 - VERTICAL FLOW NET CHARACTERIZATION, SECTION H-H'

FIGURE 12 - PROPOSED MONITORING WELL LOCATION PLAN

1.00 INTRODUCTION

Sanco, Inc. (Sanco) has contracted with Goldberg-Zoino & Associates, Inc. (GZA) to prepare a hydrogeologic study for an approximately 18-acre sanitary landfill expansion to be located on a 58.3-acre parcel east of Trudeau Road in Bethlehem, New Hampshire. The proposed landfill expansion site is shown on Figure 1. Volume I of this report presents the hydrogeologic evaluation of the site and includes tabulated data and figures pertinent to the discussion of subsurface conditions. Volume II consists of appendices containing various data generated during preparation of this and previous reports and from the on-going groundwater monitoring program.

Sanco's initial landfill expansion area permit application was denied by the State of New Hampshire, Department of Environmental Services, Waste Management Division (WMD) in August 1986. This report is submitted as part of a revised permit application package incorporating additional studies to adequately address questions raised by WMD in August 1986. The permit application package also includes design drawings, technical specifications, and a landfill operating plan prepared by Kimball Chase Company, Inc. of Portsmouth, New Hampshire, the project civil engineers. Please note that the observations and conclusions presented in this report are subject to the limitations set forth in Appendix A of Volume II.

1.10 OBJECTIVE AND SCOPE OF STUDY

The overall objective of GZA's services was to satisfy WMD permitting requirements relating to the hydrogeologic evaluation of the site. More specifically, the objectives of the hydrogeologic study were to provide additional information regarding:

1. continuity or discontinuity of the geologic units;

2. depth to bedrock surface;

3. the hydrogeologic characteristics of each geologic unit and the site as a whole;

4. the hydraulic connection of the site with adjacent properties; and

5. the hydrogeologic characteristics of the 10-foot thickness of soil below the proposed landfill base levels.

Also included within the scope of study was selecting location for a groundwater monitoring well network based on the hydrogeologic evaluation of the site. The hydrogeologic study encompassed background research, review of existing data, subsurface explorations, and laboratory analyses to gather additional data regarding site hydrogeologic conditions.

1.20 SCOPE OF WORK

Services provided by GZA to meet the project objectives included the following:

1. Review of existing data previously gathered at the site as well as other data available in technical references.

2. Performance of a seismic refraction survey to assess depth to bedrock and other detectable interfaces.

3. Observation of seven continuously sampled test borings in the landfill expansion area, eight test borings with multi-level piezometer installations located throughout the Sanco site, and two monitoring well installations downgradient of the existing landfill facility. Borehole permeability tests were performed at selected intervals.

4. Performance of two rounds of groundwater level readings in the piezometers and groundwater monitoring wells installed during the recent exploration program, and in groundwater observation and monitoring wells previously installed at the site by others.

5. Performance of 24 laboratory grain size analyses of soil samples representative of geologic units.

6. Evaluation of the geologic setting, surface and groundwater hydrology, and suitability of the site for development as a landfill.

1.30 SITE DESCRIPTION

The proposed 18-acre landfill expansion area will be situated on the 58.3-acre Sanco site located east of Trudeau Road. Sanco recently acquired property rights to a 47-acre parcel, referred to herein as parcel B, which abuts the site to the north. The site, as defined for the purposes of this report, refers to the southern (parcel A) 58.3-acre parcel.

Undeveloped forest land abuts the site to the north and southeast. Muchmore Road and a parcel of land which had been subject to sand and gravel mining in the past abut the site to the northeast. Within the Sanco site, the limits of an active 4-acre sanitary landfill are located approximately 100 feet northeast of the proposed landfill expansion area limits. A site plan is presented on Figure 2.

The site lies within a portion of a northerly draining 350-acre watershed which is part of the larger Ammonoosuc River watershed. The Ammonoosuc River flows in a general northwesterly direction adjacent to the site and is located approximately 400 feet northeast of the northeast corner of the site. There are no surface water drainage courses on the site.

Site topographic features include several hills and plateaus with a portion of the site ground surface being altered by soil mining and landfilling activities. As shown on Figure 2, maximum topographic relief is about 55 feet with elevations ranging from approximately 1318 feet site vertical datum (SVD) in the northwest corner of the site to 1373 feet SVD in the southeast corner of the site. The site vertical datum was chosen by others to approximately mean sea level (MSL). Elevations noted hereinafter refer to "approximate" mean sea level (MSL). The existing landfill currently rises approximately 22 to 42 feet above the surrounding ground surface.

Excavations which have served as a source of daily cover for the active landfill are located within eastern portions of the proposed landfill area and extend south of the existing landfill. The areal extent of the excavations is about 5 acres. Base elevations for the excavations range from about 1318 to 1332 feet MSL. Water has ponded in isolated low areas of these excavations. Those portions of the site unaltered by soil mining or landfilling activities are either forest land or recently cleared forest land.

1.40 PROJECT DESCRIPTION

A sanitary landfill is proposed for an approximate 18-acre area southwest of the active 4-acre landfill. A brief synopsis of the proposed landfill development is presented below. Refer to the Kimball Chase design drawings for more detailed information.

The landfill will be developed in four phases progressing from east to west. Perimeter swales with appropriate erosion controls will direct most runoff around the landfill development area to a sedimentation pond abutting the northwest corner of the proposed landfill. The remainder of the runoff will flow into an exfiltration pond located northeast of the active landfill. The landfill liner system will consist of a primary and secondary synthetic membrane separated by a permeable medium containing leak detection witness drains. Landfill base level elevations, defined as the bottom of refuse, will vary from approximately 1316 to 1334 MSL, from the southeast to northwest portions of the landfill area, respectively. A synthetic membrane and soil cap is proposed for closure of the landfill. A solid waste transfer station and leachate pretreatment facility are being considered for the western portion of the site. The currently active landfill is scheduled for closure in 1987.

2.00 PREVIOUS STUDIES

In June 1976, Soils Engineering, Inc. of Charlestown, New Hampshire completed four soil borings with monitoring well installations within existing landfill area. Due to subsequent expansion of this landfill area, these monitoring wells were abandoned.

In September 1984, Caswell, Eichler and Hill (CEH) of Portsmouth, New Hampshire conducted subsurface explorations as part of an hydrogeologic evaluation of the currently active landfill. Results of this evaluation were presented in a report entitled "Installation of Monitoring Wells at the Sanco Landfill, Bethlehem, New Hampshire." For this evaluation, CEH completed four test borings in which groundwater monitoring wells were installed. The ongoing groundwater monitoring program began upon completion of the monitoring wells. The monitoring network consists of one monitoring well upgradient of the active landfill, three downgradient monitoring wells, and a groundwater seep located approximately 1,200 feet northeast of the landfill.

In January 1986, CEH conducted subsurface explorations to perform a hydrogeologic evaluation of the landfill expansion area. Results of this evaluation were presented in a report entitled "Hydrogeologic Report for the Proposed Sanco Landfill Expansion, Bethlehem, New Hampshire." This report was submitted as part of Sanco's initial landfill expansion area permit application. For this evaluation, CEH completed six test borings in which four single-level groundwater observation wells and two bi-level observation wells were installed. Subsurface explorations also included five test pit excavations and a seismic refraction survey. Groundwater samples obtained from three observation wells were analyzed for volatile organic compounds (VOC's) and leachate indicator parameters.

Previous study reports, test boring and test pit logs, and groundwater observation and monitoring well installation details prepared by others are presented in Appendix B of Volume II. Locations of previous test borings, test pit excavations, and well installations are shown on the exploration location plan

(Figure 3). Groundwater quality data generated by the active landfill monitoring program as well as groundwater quality data for three landfill expansion area observation wells are included in Volume II, Appendix C. Total VOC concentrations for each well and sampling round are summarized in Table 2.

3.00 CURRENT EXPLORATIONS

GZA performed a subsurface exploration program at the Sanco site between October 1986 and February 1987. Subsurface explorations consisted of a seismic refraction survey, seventeen test borings, and two bedrock probes. Multi-level piezometers were installed at eight locations and permanent groundwater monitoring wells were installed at two locations. Groundwater levels at these locations and at previously installed groundwater observation and monitoring wells were monitored for the duration of the subsurface exploration program. Relevant subsurface information obtained from the fourteen test borings and five test pits completed previously by others was used in characterizing the site hydrogeologic conditions.

The current test borings were staked in the field by GZA. Following completion of the explorations, actual test boring locations and well reference elevations were determined by Moose Brook Land Management of Littleton, New Hampshire. Ground surface elevations of other explorations were determined by linear interpolation between existing topographic contours as presented on Figure 3. The location of bedrock probe BP-1 was determined by GZA by taping from prominent site features. Bedrock probe BP-2 was located by Sanco personnel.

Borehole permeability testing was performed during the exploration program to provide an indication of the hydraulic conductivity of the geologic units.

3.10 SEISMIC REFRACTION SURVEY

A seismic refraction survey consisting of two survey lines totalling approximately 2,700 linear feet was performed by Dr. John Kick of Dunstable, Massachusetts on October 29 and 30, 1986. The two survey lines are located on the exploration location plan. The seismic refraction survey report is included in Appendix D.

3.20 TEST BORINGS

Test borings, designated B-301 through B-308, P-1 through P-7, B-102S and B-103D, were drilled by Maine Test Borings, Inc. of Brewer, Maine between December 9, 1986 and January 29, 1987.

Boring locations are shown on Figure 3 and boring logs are included in Appendix E.

Test borings B-301 through B-307 were drilled using 3-inch NW and/or 4-inch HW casing and drive-and-wash techniques. Soil samples were recovered at 5-foot intervals to a depth of approximately 50 feet and at 10-foot intervals thereafter. Soil samples were obtained using an 18- or 24-inch long, 2-inch outside diameter (OD) split-spoon sampler which was driven with a 140-pound hammer falling 30 inches. The number of blows required to drive the sampler each 6-inch increment was recorded and is shown on the boring logs. The number of blows required to drive the sampler from 6 to 18 inches penetration is the standard penetration resistance (SPT N-value) which is an indicator of in-situ soil density. Soil samples recovered from the boreholes were visually classified by GZA personnel and stored in glass jars for future reference or laboratory testing. Test borings B-302 through B-307 were advanced 26 to 54 feet below the observed groundwater surface. Test boring B-301 was advanced to refusal in boulders and cobbles approximately 64 feet below the observed groundwater surface.

Test boring B-308 was advanced using NW and 2-3/8-inch BW casing and drive-and-wash techniques. Soil samples were not obtained as the primary purpose of this test boring was to advance casing to bedrock so that a confirmatory rock core could be obtained. This effort was abandoned when drilling equipment limitations prevented further advancement of the borehole at a depth of 90 feet.

Test borings P-1 through P-7 were advanced using solid stem augers followed by NW casing and drive-and-wash techniques. Soil samples were continuously recovered using a 24-inch long split-spoon sampler. These test borings were advanced to a depth up to 14 feet below the observed groundwater surface. The boreholes were backfilled with cement/bentonite grout upon completion.

Test borings B-102S and B-103D were advanced using NW casing and drive and wash techniques. Soil samples were obtained at 5-foot intervals in strata not previously explored by the adjacent borings B-102 and B-103. These test borings were otherwise advanced without obtaining samples.

3.30 BEDROCK PROBES

In order to verify the bedrock profile obtained from the seismic refraction survey, two bedrock probes were drilled. A water supply well drilling rig was utilized for this purpose due to the unsuccessful attempt to obtain a bedrock core using soil boring equipment at boring B-308. Bedrock probes, designated BP-1 and BP-2, were drilled by Falcon Well Drilling Company of

Lyndonville, Vermont between February 9 and 13, 1987. Bedrock probe locations are shown on Figure 3 and logs of these explorations are included in Appendix E.

The bedrock probes were drilled using a 6-inch diameter roller bit. Drilling fluid was circulated to evacuate cuttings and to maintain borehole integrity. Detectable interfaces were noted by the drilling foreman. Soil samples were not obtained due to limitations of the drilling equipment. Bedrock encounter was verified by drilling 15 feet into competent rock.

Bedrock probe BP-2 also served as the subsurface exploration for a water supply well for the proposed transfer station. This well has a design capacity of 10 to 15 gallons per minute (gpm). A pump test was performed on a zone of the overburden soil thought to be most permeable based on the drilling foreman's observations. The purpose of this test was to determine if sufficient capacity could be developed in the overburden deposits before advancing the test hole into bedrock. Deposits thought to consist of boulders, cobbles, and coarse granular material were encountered at a depth of 48 to 66 feet. The borehole below this zone was sealed with bentonite and the diameter of the remainder of the borehole was subsequently enlarged with an 8-1/2-inch roller bit. The test well consisted of a 6-inch diameter, 20-foot long, 0.008-inch slot stainless steel screen attached to the surface by a 6-inch casing. The test well was developed and pumped for two hours using air lift procedures. The test well yielded less than 1 gpm and was abandoned. A second test hole was advanced 280 feet into bedrock where sufficient capacity was encountered.

3.40 PIEZOMETER INSTALLATIONS

In order to assess hydrogeologic conditions at the site and their potential impact upon development and monitoring of the landfill, GZA installed eight multi-level piezometers. Piezometers were constructed of 3/4-inch inside diameter (ID) threaded Schedule 40 PVC pipe. The piezometer screens consisted of 0.01-inch machine slotted sections. The annulus between the borehole well and piezometer screen was backfilled with clean washed sand. Bentonite seals were placed above and below the sand pack and at 20-foot intervals in the borehole to inhibit water flow along the PVC pipe.

GZA installed two piezometers within borings B-302 through B-308. One piezometer consisting of a 2-foot screened interval was placed at the bottom of each borehole. A second piezometer was installed so that a 10-foot screened interval was situated to intersect the groundwater surface. Within boring B-301, a third 2-foot piezometer screen was placed between the lower piezometer and the 10-foot piezometer at the groundwater surface.

Piezometer construction was completed at the ground surface with a cement/bentonite grout surrounding a 3-inch protective steel casing with a vented locking cap. Piezometer installation details are shown on the individual boring logs in Appendix E. Piezometer locations are shown on Figure 3.

3.50 MONITORING WELL INSTALLATIONS

Permanent groundwater monitoring wells were installed at two locations downgradient of the existing landfill as required by the WMD. The purpose of these additional monitoring wells is to provide monitoring locations to assess vertical hydraulic gradients and variations in groundwater quality with depth. The monitoring wells were installed adjacent to existing wells B-102 and B-103 and are designated B-102S and B-103D, respectively, on Figure 3.

Permanent groundwater monitoring wells were constructed of 1-1/2-inch Schedule 40 PVC pipe. The monitoring well screens consisted of 15-foot long 0.01-inch machine slotted sections. The annulus between the borehole wall and the well screen was backfilled with clean silica-type filter sand. An approximately 2-foot thick bentonite seal was constructed above the filter sand and at approximately 20-foot intervals in the borehole to inhibit water flow along the PVC pipe. The remainder of the well was backfilled with washed sand. Monitoring well construction was completed at the ground surface with a cement/bentonite grout surrounding a 3-inch protective steel casing with a vented locking cap. Monitoring well installation details are shown on the individual boring logs in Appendix E.

3.60 BOREHOLE HYDRAULIC CONDUCTIVITY TESTING

Borehole hydraulic conductivity testing was performed at eight locations in order to estimate the hydraulic conductivity of selected geologic units. The results of a ninth hydraulic conductivity test were disregarded when stabilized groundwater level readings indicated that the test was performed in unsaturated soil. Falling head hydraulic conductivity test procedures were used in all but boring B-301 where constant head procedures were used.

Hydraulic conductivity test results are summarized in Table 3. The test procedures and field data sheets are presented in Appendix F; test results are discussed in Section 6.20.

4.00 LABORATORY TESTING PROGRAM

Soil samples recovered from the explorations performed at the Sanco site were delivered to GZA's soils laboratory for grain size analyses. Sieve and hydrometer testing was performed on selected samples in accordance with applicable ASTM standards. Laboratory test procedure details and individual test results are included in Appendix G.

5.00 SITE GEOLOGY

Although not mapped in detail, the surficial geology in the vicinity of the proposed landfill has been presented on regional maps including the Map of the Surficial Geology of New Hampshire by Goldthwait, et al (1) and on the unpublished interim Geologic Map of New Hampshire by Lyons, et al (2). The site has also been included in a regional groundwater availability map of the middle Connecticut River basin in west-central New Hampshire by Cotton (3). Two site studies previously prepared by Caswell, Eichler and Hill, Inc. (CEH) of Portsmouth, New Hampshire are included in Appendix B for reference. Conclusions presented in the above-referenced reports are generally consistent with the findings of this study, with the exception of the findings of Cotton who developed the regional groundwater availability map without the benefit of site-specific subsurface data.

5.10 GEOLOGIC SETTING

The geology of the proposed landfill expansion site and surrounding areas results primarily from sediment deposition by glacial activity during the last glacial period, the Wisconsin glacial stage. The site is located within the middle Connecticut River basin where crystalline bedrock is typically covered by unconsolidated glacial deposits. Regionally, stratified drift often occurs in the valleys of till-covered bedrock uplands.

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1. Goldthwait, J.W., C. Goldthwait, and R.P. Goldthwait, The Geology and Mineral Resources of New Hampshire - Part I, Surficial Geology, 1951.

2. Lyons, J.B., W.A. Bothner, R.H. Moench, J.B. Thompson Jr., Interim Geologic Map of New Hampshire, 1986. Office of State Geologist, Open file Map OF-86-1.

3. Cotton, J.E., Availability of Ground Water in the Middle Connecticut River Basin, West-Central New Hampshire, U.S. Geological Survey Open File Report, Water Resources Investigations 76-18, prepared in cooperation with the New Hampshire Water Resources Board, 1976.

Morphologic features of the site and immediate surrounding areas are characteristic of a glacial kame terrace. The terrace is orientated in an upland area along a narrow, steeply sloping side of the Ammonoosuc River valley.

At this site, the terrace was formed in a glacial environment which produced upper and lower glacial till units separated by ice-contact stratified drift. The overburden (glacial) deposits vary in thickness from approximately 113 feet in the western portion of the site to over 250 feet in eastern portions of the site. The glacier directly deposited the lower glacial till unit over bedrock. The ice contact stratified drift was deposited in contact with or in close proximity to the glacial ice in the following manner. During the glacial advance, relatively temperate conditions produced meltwater streams which formed beneath and adjacent to the glacier. The meltwater streams transported and deposited a wide variety of sediments including silts, clays, sands, and gravels which caused the formation of the ice contact stratified drift deposits. Silts and clays were deposited in ponds which may have formed under the ice in shallow depressions or kettles, or in small lakes formed by down-valley ice dams.

The silts and clays may have been partially eroded by meltwater streams of higher velocity and energy which in turn deposited coarser sediments primarily consisting of sands and gravels. The terrace was subsequently overridden by glacial ice which compacted the stream and pond sediments and deposited additional glacial till. Following the last glacial retreat, stream erosion of the dense glacial sediments has caused the widening and deepening of the valley to its present shape.

Glacial till is deposited directly under glacial ice and consists of a very dense, non-stratified, heterogeneous mixture of clay, silt, sand and gravel size particles. Stratified drift is comprised of layers of gravel, sand, silt and clay which is sorted during transport by meltwater streams. Ice-contact stratified drift deposits typically exhibit an extreme range and abrupt change in grain size which reflects the immediate proximity of stagnant glacial ice during deposition. Accumulation may occur beneath, upon or against the terminal zone of the glacier and is commonly sporadic. Within a site, depositional environments may include a swift stream, a quite pool, a debris flow, overriding by ice, folding and faulting of sediment layers or the accumulation of glacial till. The wide fluctuations in depositional environments form sediment layers which are discontinuous and irregular.

5.20 GEOLOGIC MATERIALS

The typical stratigraphic sequence observed at this site, in ascending order, is bedrock, glacial till, ice-contact stratified drift, and glacial till. Figures 4 through 6 depict subsurface profiles which shows GZA's interpretation of the stratigraphic sequence beneath the site. The locations of these profiles are shown on Figure 3. These profiles indicate the vertical and horizontal distribution of geologic materials at the given locations. In addition to soil samples collected during GZA's drilling program, soil samples obtained from test borings B-101 through B-104 and B-201 through B-206, completed as part of CEH's previous site investigations, were examined in GZA's soils laboratory in order to interpret subsurface conditions. The profile descriptions are based on the predominant particle size of each sample, although samples typically were poorly sorted and contained varying proportions of silt, sand, and gravel components. The wide range of dominant particle sizes both horizontally and vertically, in addition to the overall very dense consistency of the soils, indicates rapidly changing depositional environments which may have occurred beneath or directly adjacent to relatively temperate glacial ice.

The various geologic materials depicted on the profiles are described in stratigraphic sequence from bedrock to the uppermost till in the following subsections.

5.21 Bedrock and Bedrock Topography

Bedrock outcrops were not observed at or in the vicinity of the site. Subsurface explorations, which consisted of a seismic refraction surveys and test borings, indicate a substantial overburden thickness. Bedrock underlying the site is classified on the interim Geologic Map of New Hampshire (4) as a moderately to well foliated pink biotite granite within the Oliverian Plutonic Series of probable Silurian to late or middle Ordovician age.

Limited data are available to characterize the bedrock surface as each test boring completed to date at the site failed to reach the bedrock surface. The 300-series test borings, completed by GZA in January 1987, were advanced to a depth ranging from approximately 76 feet to 115 feet below the ground surface without encountering bedrock. Presently, information on the bedrock surface is limited to two bedrock probes (BP-1 and BP-2) and seismic data generated during this and previous studies.

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4. Lyons, J.B., et al eds, 1986.

Bedrock probe BP-1, located in the northeastern portion of the site, contacted bedrock at a depth of approximately 254 feet. Bedrock probe BP-2, located in the western portion of the site, encountered bedrock at a depth of about 113 feet. Each probe was advanced approximately 15 feet into bedrock to confirm the overburden/bedrock contact.

A seismic profile generated from along a generally west to east traverse indicates that the bedrock surface slopes from an estimated depth of 60 feet in the western portion of the site to approximately 250 feet in the eastern portion. A north-south seismic profile indicates that the bedrock surface also slopes southward from a depth of approximately 88 feet at the northern site boundary to about 125 feet near the center of the site. Seismic data along the eastern property line, reported by CEH in 1984, indicate bedrock is at a depth of 200 feet approximately 400 feet northeast of the existing landfill and over 160 feet deep adjacent to the east-southeast corner of the existing landfill.

Test boring and bedrock probe data generally correlate with seismic data except in the area of seismic shot point 1 in the western portion of the site where the estimated depth to bedrock from the seismic survey at this location is approximately 60 feet. Contact with the bedrock surface was confirmed at a depth of 113 feet at BP-2 which is located approximately 200 feet southeast of seismic shot point 1. Descriptions of subsurface materials observed at BP-2 indicate the presence of a very dense, gravelly till at a depth of about 68 feet. The undetected presence of this very dense lower till overlying bedrock in the vicinity of shot point 1 may have affected the interpretation of the seismic data and caused the depth to bedrock to be underestimated.

5.22 Lower Glacial Till

Granular till was encountered at depths below ground surface varying from 56 to 92 feet in the 300-series test borings and in test borings B-102 and B-103D. The elevation of the top of the lower till unit varied between approximately 1255 and 1290 feet MSL. The thickness of this unit ranged from greater than 4 feet at test boring B-302 to greater than 28 feet at test boring B-305. As discussed in Section 5.10, the lower till unit was deposited directly under glacial ice and likely continues to bedrock.

The lower till generally varies in composition from a fine to coarse sand, trace to some silt, trace gravel, to a fine to coarse sand and gravel, little silt with occasional cobbles and boulders. The lower till was observed to be very dense as evidenced by SPT N-values which ranged from 129 blows per foot to 200 blows per foot for a 3-inch penetration.

5.23 Ice-Contact Stratified Drift

Ice-contact stratified drift deposits were encountered in each test boring with the exception of test boring B-305 where this unit was apparently removed by subsequent glacial advance. Stratified drift was encountered at depths below ground surface ranging from 5 to 57 feet. Stratified drift was observed at the ground surface on excavation faces south and southeast of the existing landfill. The elevation of the top of this unit varied between approximately 1285 and 1345 feet MSL. The thickness of this unit, where encountered, ranged from 10 feet at test boring B-102 to 60 feet at test boring B-303. Several shallower test borings did not fully penetrate the stratified drift deposits.

The ice-contact stratified drift is comprised of distinct discontinuous subunits of silt and gravelly sand which occur within a sand matrix. The sand matrix consists of a fine to coarse sand, with trace to little silt, trace to little gravel, with occasional 3/4- to 2-inch laminations of silt. This sand is differentiated from the sand deposits of the lower glacial till by the silt laminations, where present, and by a slightly lower overall silt content. Due to the similarity of the sand deposits of the stratified drift and lower glacial till, the contact between these units is occasionally obscure. The sand matrix within the stratified drift was observed to be very dense having SPT N-values ranging from 87 blows per foot to 125 blows for a 2-inch penetration. The following sections describe the extent and composition of the silt and gravelly sand subunits of the stratified drift deposits.

5.23.1 Silts

The silt deposits within the stratified drift were observed to be largely discontinuous within the study area due to the depositional environment discussed in Section 5.10. Stratified drift silt deposits were encountered in test borings B-101 through B-104, B-204, B-205, B-302 through B-304, B-306, and P-5 through P-7. Where encountered, the thickness of this unit ranged from 2 feet at test boring P-6 to 17 feet at test boring B-103/103D. The thickest and most laterally continuous occurrence of this deposit was encountered in the north and northeastern portion of the site as depicted on profiles C-C' and E-E'. The stratified drift silt deposit consists of silt to silt and clay with trace amounts of fine sand. The silt deposit was observed to be very dense with SPT N-values ranging from 78 blows per foot to 100 blows for a 3-inch penetration.

5.23.2 Gravelly Sands

The gravelly sand deposits within the stratified drift were observed to be discontinuous within most portions of the study area. Stratified drift gravelly sand deposits were encountered in test borings B-103, B-202, B-204, B-301, B-303, B-304, B-306, and P-5 through P-7. Where encountered, the thickness of this subunit ranged from 2 feet at test boring P-7 to 30 feet at test boring B-301. The gravelly sands were deposited by high energy meltwater streams which may have eroded into the surface of the underlying silt and sand deposits.

Stratified drift gravelly sand varies in consistency from gravel with little sand, trace silt, to fine to coarse sand with some gravel and trace to little silt. This gravelly sand subunit is differentiated from the gravelly sand deposits of the lower glacial till by its more angular gravel-sized particles and slightly lower silt content. Stratified drift gravelly sands were observed to be very dense with SPT N-values ranging from 50 blows per foot to 150 blows for a 3-inch penetration.

5.24 Upper Glacial Till

Glacial till was encountered at the ground surface in each test boring to depths ranging from 5 to 57 feet. As discussed in Section 5.10, glacial till is typically a non-stratified, heterogeneous mixture of soil particle sizes. The upper glacial till varies widely in composition, with depth and between borings, from fine to coarse sand, with trace to some silt, trace to little gravel, to silty fine sand, to sandy silt, to silt, to clayey silt. The variations within the glacial till occur without an apparent pattern. Due to the non-stratified nature of this deposit, as suggested by the subglacial ice mode of deposition and supported by observations of the glacial till in exposed excavations and in the test borings, correlation between the glacial till subunits was not attempted as this would present stratigraphy which is not believed to exist.

The upper glacial till soils were observed to be medium dense near the ground surface and very dense at depth with SPT N-values ranging from 17 blows per foot to 150 blows for a 3-inch penetration.

The silt and clayey silt deposits of the upper glacial till are differentiated from the stratified drift silt deposits by the presence of trace to little amounts of fine to coarse sand and gravel, indicative of a subglacial ice deposition. The absence of sands and gravels in the stratified drift silts is indicative of the well sorted, low energy (pond) depositional environment.

The fine to coarse sand deposits of the upper glacial till are differentiated from the stratified drift sand deposits by its slightly higher silt content. Due to the similar composition of these sand deposits, the contact between the upper glacial till and the stratified drift is occasionally obscure.

6.00 SITE HYDROLOGY

6.10 SURFACE WATER HYDROLOGY

The surface water drainage area, defined by the watershed boundary which contains the proposed 18-acre landfill expansion area, is shown on Figure 7. As discussed in Section 1.30, this watershed occupies an area of approximately 350 acres and represents a portion of the Ammonoosuc River watershed. The watershed area is drained by a northeasterly trending stream which is tributary to the Ammonoosuc River. The stream is located about one-quarter mile northwest of the site. There are no surface water drainage courses on the site., The southeastern boundary of the watershed area represents a regional watershed and groundwater divide with the Gale River portion of the Ammonoosuc River watershed to the south.

6.20 GROUNDWATER HYDROLOGY

6.21 Hydraulic Characteristics of Subsurface Materials

Parameters which describe the hydraulic characteristics of subsurface materials at the site are hydraulic conductivity (permeability) and saturated thickness. Hydraulic conductivity is the capacity of a given material to transmit water. It represents the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Hydraulic conductivity is commonly expressed in terms of centimeters per second (cm/sec) or feet per day (ft/day). Saturated thickness is the fully saturated portion of a subsurface material measured vertically, most commonly between a layer of relatively low permeability material such as bedrock or clay and the top of the groundwater table.

Two methods were used during this study to estimate the hydraulic conductivity of subsurface materials at the site. Hydraulic conductivity was measured in the field at various soil boring locations by performing borehole falling head tests within selected soil units. These tests were conducted as "wick" tests and have been evaluated using standard methods as outlined in Appendix F. In addition, laboratory gradation analyses were performed on representative soil samples obtained from selected soil boring locations across the site. The gradation analyses were evaluated using the Kozeny-Carman relationship to quantitatively estimate the hydraulic conductivity of the soil sample. Hydraulic conductivity values derived using both methods are included in Table 3.

Results of borehole falling head tests and laboratory soil gradation analyses using the Kozeny-Carman relationship indicate that most subsurface materials at the site are of relatively low hydraulic conductivity. As a result of consolidation from over-riding glaciers and the heterogeneous mixture of gravel, sand, and silt size soil grains, glacial till soils typically have a significantly lower porosity, and consequently a significantly lower hydraulic conductivity than the more homogeneous gravelly sand deposits within the stratified drift. Estimated hydraulic conductivities of the gravelly sand deposits within the stratified drift range from 24 ft/day (8x10E-3 cm/sec) to 31 ft/day (1.1x10E-2 cm/sec). Lower hydraulic conductivities ranging from 0.08 ft/day (2.8x10E-5 cm/sec) to 1.5 ft/day (5.3x10E-4 cm/sec) are indicated for the other stratified drift deposits and glacial till.

The borehole falling head test results at test boring B-307 from a depth of 80 to 81.5 feet were judged to be anomalous. The anomaly may have resulted from water flowing upward between the contact of casing and the surrounding soil instead of into the soil unit being tested. The estimated hydraulic conductivity of 9.2 ft/day (3.2x10E-3 cm/sec) is over one order of magnitude higher than that of similar deposits. Also, the results of this test did not correlate with the Kozeny-Carman estimate in the same manner as other tests as shown on Table 3.

A pump test was conducted at bedrock probe BP-2, located at the western side of the site, to evaluate potential well yield for use at the proposed transfer station. The pump test was performed within a saturated zone of coarse granular material which drilling observations indicated was predominantly composed of gravel, cobbles, and boulders. This unit was estimated to be the most permeable strata encountered during advancement of the probe hole through the overburden deposits.

A 6-inch diameter screen was installed from a depth of 45 feet to 65 feet within the probe hole. Following a well development period of approximately two hours, the discharge rate was estimated to be approximately one gallon per minute (gpm). The well yield was determined to be too low for future use and the well was abandoned. The low well yield indicates that the gravel, cobbles, and boulders may have been surrounded by a fine soil matrix resulting in a low transmissivity which is characteristic of the lower glacial till. Alternately, this unit may have been highly transmissive, but discontinuous and quickly drained, which is characteristic of the gravelly sand deposits within the stratified drift. The pump test results are indicative of deposits which have low potential to yield water in sufficient quantities for residential, municipal, or industrial water supply requirements.

The landfill base subgrade soils consist of the upper glacial till and, to a lesser extent, the fine grained deposits of the stratified drift. Borehole falling head tests were not performed in these deposits since subgrade soils were above the groundwater table. Examination of borehole tests on similar soils at depth, Kozeny-Carman analyses, and laboratory grain size distribution curves indicate that the hydraulic conductivity of the landfill base subgrade soils would vary from 0.1 ft/day (3.5x10E-5 cm/sec) to 1.5 ft/day (5.3x10E-4 cm/sec).

6.22 Groundwater Levels and Flow Direction

A total of eight observation wells and four groundwater monitoring wells were installed in boreholes at ten locations across the site during the previous studies by CEH to assess subsurface conditions. As discussed in Section 3.00 of this report, an additional 17 observation wells and two groundwater monitoring wells were installed during the recent subsurface exploration program conducted by GZA. At eight locations, multi-level observation wells were constructed to observe groundwater conditions at various depths.

Groundwater levels were measured at a total of up to 31 locations during recent and previous subsurface exploration programs. Groundwater elevations and the dates these elevations were observed are presented in Table 1. Groundwater observations made during drilling are noted on the boring logs included in Appendix E.

Groundwater levels measured at the 100-series wells from September 17, 1984 to February 4, 1986 show an overall decrease ranging from 3.4 feet to 4.4 feet. These same wells measured from February 4, 1986 to February 12, 1987 indicate a decrease in groundwater levels ranging from 0.7 feet to 1.2 feet. The 200-series wells measured over the same one-year period follow the pattern of the 100-series wells and show a similar decrease. The steady drop in groundwater levels across the site from September 17, 1984 to February 12, 1987 is likely the result of a slight decrease in regional precipitation during this period.

Groundwater levels obtained on February 12, 1987, were used to prepare the groundwater elevation contour maps shown on Figures 8 and 9. The February 12, 1987 measurements were used since they are the only fully stabilized and complete set of groundwater levels for the site.

Groundwater levels observed at the site ranged from 10 to 66 feet below ground surface. Groundwater elevation contours prepared using the upper observation wells are shown on Figure 8. These observation wells are screened across the surface of the groundwater table in the upper glacial till or stratified drift. Figure 8 indicates that groundwater within these deposits moves in a generally northwesterly to northeasterly direction from the site toward the Ammonoosuc River. Observed groundwater levels at other times, shown in Table 1, would result in contours similar to those depicted on Figure 8, though shifted to reflect fluctuations in the seasonal water table. As shown on Figure 8, a local north-south oriented groundwater divide exists through the landfill expansion area. Groundwater east of the divide flows northeasterly, whereas groundwater west of the divide flows northwesterly.

Groundwater elevation contours prepared using the lower observation wells are shown on Figure 9. These observation wells, with the exception of B-204, are screened in the lower glacial till. As shown on Figure 9, convergent groundwater flow occurs in an east-northeasterly direction within the lower glacial till.

Groundwater seeps occur on the steeply sloped bank of the Ammonoosuc River approximately 1,200 feet northeast and downgradient of the existing landfill. The elevation at the uppermost seep was reported by CEH (1984 study) to be approximately 70 feet above the river. This elevation approximately coincides with a projected groundwater surface extrapolated from Figure 8. Groundwater breaks out of the slope at this elevation due to the abrupt drop in the ground surface caused by erosion of the glacial kame terrace by the Ammonoosuc River.

The uppermost seep, which is sampled during the active landfill groundwater monitoring program, appears to flow at a rate higher than other seeps occurring near the same elevation or further down the slope. Further, large areas of the slope below the uppermost seep outbreaks are dry. The observed variation in seepage rates along the river bank indicate that preferential flow paths exist, at least locally, due to exposure of subsurface materials which are more permeable than the surrounding soil. A direct stratigraphic connection cannot be inferred between the Sanco site and the seep, since subsurface information is not available in this area; however, in terms of hydrogeologic setting, the elevation of the uppermost seep appears to approximately coincide with that of the lower till unit.

6.23 Hydraulic Gradients and Seepage Velocities

The hydraulic gradient, or change in hydraulic head per unit of distance, varies with location across the site. Hydraulic gradients ranging from 0.002 to 0.044 foot/foot (ft/ft) were estimated at the site along the directions of groundwater movement based upon the groundwater elevation contours shown on Figure 8. Within the southern portion of the site, hydraulic gradients range from 0.002 to 0.003 ft/ft and reflect the proximity of this portion of the site to the regional watershed and groundwater divide. Within the northwestern portion of the site, hydraulic gradients range from 0.024 to 0.033 ft/ft. Groundwater flow patterns in this area are discussed in more detail below. Within the northeastern portion of the site, hydraulic gradients range from 0.024 to 0.044 ft/ft and reflect the more steeply sloping terrain of the Ammonoosuc River valley.

Vertical gradients of groundwater movement were estimated using groundwater elevations at multi-level observation well locations. West of the site groundwater divide, upward vertical gradients of 0.08 and 0.006 ft/ft were measured at well locations B-308 and B-202, respectively. At well location B-301, a downward vertical gradient of 0.068 ft/ft between the upper and middle wells and an upward vertical gradient of 0.17 ft/ft between the lower and middle wells were measured. A vertical gradient of zero, indicative of horizontal flow, was measured at well location B-307.

Groundwater levels measured in multi-level wells B-301, B-202, and B-307 were used to prepare the vertical flow net shown on Figure 10. This figure is intended to portray vertical groundwater flow west of the site groundwater divide. The convergent flow at location B-301 suggests that the 31-foot thick gravelly sand deposit (stratified drift) encountered at a depth of 33 feet is acting as a preferential groundwater flow path. This deposit controls groundwater flow in that it receives flow from the less permeable upper and lower till units and essentially drains, in a northwesterly direction, that portion of the site west of the groundwater divide.

A comparison of Figures 9 and 10 indicates that groundwater in the lower till unit generally flows in an east-northeasterly direction, a component of which enters the stratified drift and subsequently flows in a northwesterly direction west of the groundwater divide. It should be noted that water infiltrating from the ground surface west of the groundwater divide would flow through the upper till and into the stratified drift, thereby following groundwater flow in the northwesterly direction shown on Figure 8. The upward vertical gradients exhibited in the lower till would inhibit a deeper flow path.

East of the groundwater divide, downward vertical gradients indicative of recharge areas were measured at most multi-level monitoring well locations. The largest vertical gradients occurred in the north-central portion of the site at observation wells B-302 (0.22 ft/ft), B-303 (0.22 ft/ft), and B-204 (0.71 ft/ft).

Groundwater levels measured in multi-level wells B-307, B-303, and B-304 were used to prepare the vertical flow net characterization shown on Figure 11. This figure is intended to characterize regional groundwater flow and the hydrogeologic connection between the site and the Ammonoosuc River. Suggested groundwater flow patterns exhibit a downward vertical component of flow (i.e., recharge) in the north-central areas of the site and subsequent upward flow and discharge out of the Ammonoosuc River bank and directly into the river system. Actual groundwater flow patterns at depth should be expected to vary from those shown since groundwater data were extrapolated a considerable distance down to bedrock and northeast to the river. Bedrock was assumed to be relatively impermeable, thus representing a no-flow boundary. The overburden soils were assumed to be homogeneous and isotropic.

As discussed in Section 6.22 and shown on Figure 9, groundwater elevation data in the lower glacial till indicate convergent groundwater flow in an east-northeasterly direction. Horizontal flow gradients change from 0.021 ft/ft between observation wells B-307D and B-204D, to 0.004 ft/ft between observation wells B-204D and B-304D. The convergent flow pattern and flattened gradients suggest the existence of a more transmissive stratum in the northeast portion of the site within or hydraulically connected with the lower glacial till. The apparent downgradient location of the monitored seep with respect to this more transmissive stratum suggests the possibility that they are hydraulically connected.

Groundwater movement through subsurface materials is a function of the hydraulic gradient and material characteristics. In subsurface soils at the site which contain layers of materials with varying hydraulic characteristics, water movement is governed by the relative permeabilities of the different soil units. Seepage velocities in less permeable glacial till, and sand, silt and clay units within the stratified drift deposits would be relatively slow. Conversely, flow in the more permeable gravelly sand units of the stratified drift deposits would be more rapid. The velocity at which groundwater travels through the soil is determined using a form of Darcy's Law:

$$V = \frac{Ki}{n}$$

where V = seepage velocity, ft/day
K = soil hydraulic conductivity (permeability), ft/day
i = hydraulic gradient, ft/ft
n = soil porosity, dimensionless

West of the groundwater divide, the predominant groundwater flow path is through the gravelly sand unit within the stratified drift deposit. Assuming an average hydraulic gradient of 0.029 ft/ft, a porosity of 0.35, and soil hydraulic conductivities between 24 and 31 ft/day, estimated seepage velocities would be in the range of 2.0 to 2.6 ft/day.

East of the groundwater divide, groundwater flow in the stratified drift is controlled by the less permeable silt, clay and sand deposits since the gravelly sand deposit is discontinuous. Assuming an average hydraulic gradient of 0.02 ft/ft, a soil porosity of 0.25, and soil hydraulic conductivities of between 0.08 and 1.5 ft/day, estimated seepage velocities would be in the range of 0.006 to 0.1 ft/day. As discussed above, groundwater flow in the lower glacial till unit east of the groundwater divide is affected by a more transmissive stratum at depth. Since the hydraulic conductivity and soil porosity of this stratum are likely similar to those of the gravelly sand deposits of the stratified drift, and assuming a hydraulic gradient of 0.004, estimated seepage velocities in this unit would be in the range of 0.27 to 0.35 ft/day.

6.24 Groundwater and Surface Water Quality

A groundwater and surface water sampling and analysis program has been conducted at the site as part of previous site studies by CEH. The program began after the installation of the 100-series groundwater monitoring wells in September 1984. A summary of the total volatile organic compounds (VOC's) is presented in Table 2.

Downgradient sampling locations include monitoring well B-101, which is located north of the existing landfill facility, and B-102, B-103 and a seep, located northeast of the existing facility. Monitoring well B-104 is located southwest and upgradient of the existing landfill. Observation wells B-201, B-202D and B-205, installed in February 1986, are located upgradient of the existing landfill in the west-central portion of the site in an area designated for the proposed landfill expansion.

Total VOC's were used to evaluate groundwater quality due to their mobility in groundwater and because they are not naturally occurring substances. Total observed VOC concentrations range from trace (present below detection limit) in monitoring well B-104 to 2440 parts per billion (ppb) in monitoring well B-102, in samples collected on September 17, 1984. More recent results obtained from samples obtained on November 25, 1986 range from zero (not detected) in monitoring well B-104 and the seep to 1105 ppb of total VOC's in monitoring well B-102.

Monitoring well B-102 has usually encountered the highest concentrations of VOC's observed in the study area. Since this monitoring well is downgradient of only a small portion of the active landfill, its groundwater quality may be due to its proximity (100 feet) to the active landfill, or possibly to its proximity to a VOC source within the landfill.

Monitoring well B-103 is located directly downgradient of the landfill at a distance of 250 feet. VOC concentrations at this monitoring well are generally lower than those at monitoring well B-102. This pattern may reflect in part monitoring well B-102's greater distance from the landfill, and subsequent relatively greater dilution of VOC concentrations.

Monitoring well B-101 appears to be located sidegradient of the landfill and its low VOC concentrations suggest that it is located on the fringe area of groundwater passing beneath the active landfill.

Upgradient of the active landfill, observed groundwater quality is considered to be representative of background conditions, even though occasional trace levels of VOC's were observed in monitoring well B-104. These trace levels detected have not occurred consistently. Results indicate VOC's were not detected in samples obtained from monitoring wells B-201, B-202D and B-205.

Considering the occurrence of VOC's in the groundwater seep, as shown in Table 2, and evidence of a more transmissive stratum within the lower glacial till unit beneath the site, it is likely that a preferential groundwater flow path from the site to the seep area exists. It should be noted that other sources not on Sanco property could be impacting water quality in the seep area. For example, an apparently uncontrolled fill area was observed 30 to 50 feet upslope and approximately 50 feet southeast of the seep outbreak.

6.30 SUMMARY OF HYDROGEOLOGIC FINDINGS

Key observations from the field exploration program relating to hydrogeologic conditions at the site are summarized below.

a. The study area, including the proposed landfill expansion area, is underlain by a sequence of very dense glacial sediments comprised of a lower till overlain by stratified drift, which in turn is overlain by an upper glacial till.

b. The bedrock surface is present at a depth of approximately 113 feet in the western portion of the site and slopes northeastward to a depth of over 250 feet.

c. The stratified drift deposit within the Sanco site is composed of very dense, generally discontinuous units ranging from silts and clays to sands and gravelly sands. The glacial till deposits within the Sanco site are composed of a non-stratified, heterogeneous mixture of clay, silt, sand, and gravel size particles.

d. Hydraulically, the gravelly sand unit within the stratified drift deposit represents the most permeable subsurface material observed at the site, ranging in hydraulic conductivity from 24 to 31 ft/day. Glacial till soils and the sand, silt and clay units within the stratified drift deposits are materials of lower hydraulic conductivity ranging from 0.08 to 1.5 ft/day.

e. An approximate 20-foot thick stratum, judged to be the most permeable overburden unit encountered in bedrock probe BP-2, yielded approximately 1 gpm during a pump test. The pump test results are indicative of deposits which have low potential to yield water in sufficient quantities for residential, municipal, or industrial water supply requirements.

f. The landfill base subgrade soils were observed to consist of upper glacial till and, to a lesser extent, fine grained deposits of stratified drift. Estimated hydraulic conductivities of these soils vary from 0.1 ft/day to 1.5 ft/day.

g. Groundwater levels observed at the site range from 10 to 66 feet in depth. A local north-south oriented groundwater divide exists within the stratified drift and upper till deposits and traverses the landfill expansion area, as shown on Figure 8. Within these deposits, groundwater to the west of the divide (in the western portion of the landfill expansion area) flows northwesterly, eventually discharging into the Ammonoosuc River; whereas groundwater to the east of the divide (in the eastern portion of the landfill expansion area and active landfill area) flows northeasterly, also eventually discharging to the Ammonoosuc River. Within the lower glacial till, groundwater flow occurs in a generally northeasterly direction across the Sanco site, as indicated on Figure 9.

h. Groundwater hydraulic gradients range from 0.002 to 0.044 ft/ft, with the highest gradients occurring in the northwestern and northeastern portions of the site. Observed vertical gradients indicating groundwater recharge areas are primarily located in the north-central portion of the site. Upward vertical gradients generally occur within western portions of the site.

i. West of the groundwater divide, the predominant groundwater flow path is through the gravelly sand within the stratified drift where estimated seepage velocities would range from 2.0 to 2.6 ft/day. East of the groundwater divide, estimated seepage velocities would range from 0.006 to 0.1 ft/day in the stratified drift, and 0.27 to 0.35 ft/day in the lower glacial till.

j. Water quality data indicate that groundwater affected by leachate from the active landfill is migrating from the active landfill in the eastern portion of the site in a northeasterly direction toward the Ammonoosuc River, likely in part through a preferential groundwater flow path from the Sanco site to seep outbreaks northeast of the site.

6.40 LANDFILL DEVELOPMENT HYDROGEOLOGIC CONSIDERATIONS

6.41 Landfill Base Level

Base level elevations for the proposed landfill expansion, defined as the bottom of refuse placement, are depicted on subsurface profiles A-A', B-B', D-D', F-F', and G-G' on Figures 4 through 6. The base level elevations will vary from approximately 1316 to 1334 MSL, from the northwest to southeast portions of the landfill area, respectively. The primary synthetic liner will be separated from refuse by 18 inches of sand. Please refer to the Kimball Chase drawing entitled "Site Development and Initial Base Grade Preparation" dated March 1987 for a more detailed depiction of the base grade elevations.

Comparison of the groundwater elevation contours shown on Figure 8, the above-referenced Kimball Chase drawings, and the subsurface profiles on Figures 4 through 6 indicates that the primary synthetic liner will be at least 11 feet above the groundwater surface as measured on February 12, 1987 throughout the 18-acre expansion area. Historical water level data presented in Table 1 suggest that the maximum fluctuation above the February 12, 1987 levels in the landfill expansion area is about 4 feet as observed at B-104. The proposed base levels thereby would provide at least 7 feet of separation above historical observed high groundwater levels, effectively isolating the landfill liner system from anticipated groundwater levels at the site.

As noted in Section 5.00, the bedrock surface was encountered at a depth in excess of 100 feet in the landfill expansion area. As such, the bedrock surface will not impact development of the landfill.

6.42 Landfill Base Subgrade Characteristics

Based upon subsurface information generated as part of this and previous studies, the landfill base subgrade soils are expected to consist of the upper glacial till and, to a lesser extent, the fine grained units of the underlying stratified drift deposit. A few topographically low areas, representing approximately 1 acre of the total landfill expansion area, will require fill placement to achieve the proposed subgrade. Available data indicate that relatively low hydraulic conductivity soils are present within a 10-foot thickness beneath the proposed landfill base level.

The overburden deposits in the vicinity of the landfill expansion area were observed to be very dense as evidenced by SPT N-values which typically exceeded 100 blows per foot. The very dense nature of these deposits is attributed to consolidation from the intense weight of the overriding glaciers and a compact structure due to the heterogeneous mixture of soil grain sizes. Considering its stress history and structure, elastic or consolidation settlement of the subsoil due to the weight of refuse will be negligible. Likewise, the landfill and its foundation is stable regarding a deep-seated slope failure because the above-mentioned mode of deposition and grain size distribution characteristics result in subsoil of high shear strength.

6.43 Summary

The proposed landfill design provides for a double lined system which significantly reduces the potential for a leachate release into the subsurface soil and groundwater. The data and hydrogeologic findings presented in this and previous reports provide the basis to monitor groundwater quality and to remediate groundwater in the unlikely event that the proposed landfill expansion would adversely impact downgradient groundwater quality. Based upon an understanding of the relationship among geologic units and of groundwater flow at the site, the groundwater monitoring wells can be located accordingly.

West of the groundwater divide, the gravelly sand within the stratified drift is the predominant flow path, where estimated seepage velocities range from 2.0 to 2.6 ft/day. The gravelly sand essentially drains this portion of the site in a northwesterly direction. Upward vertical gradients in the lower glacial till would inhibit a deeper contaminant migration path. Groundwater monitoring within the gravelly sand deposit would therefore detect contaminants emanating from the landfill expansion area west of the groundwater divide.

East of the groundwater divide, slower groundwater flow occurs relative to the area west of the divide. Estimated seepage velocities in this area range from 0.006 to 0.1 ft/day in the stratified drift, and 0.27 to 0.35 ft/day in the lower glacial till. Due to downward vertical gradients exhibited in this area, contaminant migration into both the stratified drift and lower glacial till would be expected. As such, both the stratified drift and lower glacial till will be monitored.

In consideration of the landfill design to be implemented at the site and the hydrogeologic setting of the site; such as the considerable depth to bedrock, the separation between the proposed landfill base levels and observed and anticipated groundwater levels, the relatively low hydraulic conductivity soils present within a 10-foot thickness beneath proposed landfill base levels, and the negligible settlement and inherent stability of the proposed landfill due to the structure and density of the subsoil; the site appears well suited for landfill development.

7.00 GROUNDWATER QUALITY MONITORING

The intent of the groundwater quality monitoring program for the landfill expansion area is to provide a mechanism for monitoring the quality of groundwater upgradient and downgradient of the landfill expansion area. The recommended monitoring well network has been developed based upon an understanding of subsurface conditions on and in the vicinity of the site, including observed groundwater flow patterns as discussed in Section 6.20 and depicted on Figures 8 through 11. In addition to groundwater quality monitoring discussed below, the ongoing groundwater quality monitoring program for the active landfill will continue.

7.10 SAMPLING LOCATIONS

Permanent groundwater monitoring wells will be installed at six locations. The monitoring well network will consist of five monitoring wells located downgradient of the landfill area and one located in an upgradient setting. These wells, designated B-401 through B-406 on Figure 10, will be located within 167 feet of the landfill area, in a manner consistent with requirements of WS 410.

In consideration of the hydrogeologic characterization of the site, dual-level monitoring wells will be installed at each downgradient location. Proposed monitoring well pairs B-402 and B-403 will be located west of the observed groundwater divide. Upper monitoring wells will be screened to intercept the observed groundwater table. The upper monitoring wells will likely be screened in the upper glacial till. The lower monitoring wells will be screened in the gravelly sand deposits within the stratified drift, which appears to be the preferred groundwater flow path for this part of the site.

Proposed monitoring well pairs B-404 through B-406 will be located east of the groundwater divide. Upper monitoring wells will be positioned to intercept the observed groundwater table, most likely in the stratified drift deposits. In consideration of the observed downward vertical gradients in this portion of the site, the lower monitoring wells will be screened in the lower glacial till. The exact placement of the screened intervals for each monitoring well will depend on subsurface conditions encountered. Monitoring wells B-405 and B-406 will be located between the proposed landfill expansion area and the active landfill; this placement will allow groundwater quality downgradient of each landfill to be monitored separately.

Because existing upgradient monitoring well B-104 lies within the proposed landfill expansion area, it will be replaced with proposed monitoring well B-401 which will serve as the upgradient monitoring well for the entire Sanco site.

7.20 MONITORING WELL INSTALLATION PROCEDURES

Test borings will be advanced using drive and wash techniques. Wash water will be obtained from a potable source. Soil samples will be collected at 5-foot intervals for the first 50 feet and at 10-foot intervals thereafter.

A groundwater monitoring well will be installed in each completed boring using the placement criteria discussed in Section 7.10. Wells will be constructed of 1-1/2-inch Schedule 40 PVC screen and riser pipe. Screened sections will be at least 10 feet long with 0.01-inch slots. Length of screened intervals will be contingent upon subsurface conditions encountered in each borehole. Flush joint threaded pipe will be used to avoid the use of PVC cements or glues. The annulus between the well screen and borehole walls will be backfilled with clean filter sand. Bentonite seals will be placed as necessary to hydraulically isolate screened intervals. Bentonite/cement surface seals will be placed to reduce surface water infiltration into the wells. Lockable protective steel casings will be installed at the ground surface to limit unauthorized tampering with the well installations.

7.30 SAMPLING PROCEDURES

Groundwater samples will be collected in accordance with relevant EPA protocols. Prior to sampling groundwater monitoring wells, a water level reading will be taken within each well. A minimum of three well casing volumes will be purged from each well with a pre-cleaned stainless steel bailer to remove stagnant water. One bailer will be dedicated for use at each well. Following purging, groundwater samples will be obtained with the same bailer. Measurements of pH, specific conductance, and temperature will be taken in the field. Samples will be collected in appropriate sample containers and preserved in accordance with EPA protocols prior to transportation to a State-approved water quality analytical laboratory. Samples will be collected and transported in accordance with EPA chain-of-custody protocols.

7.40 SCOPE OF ANALYTICAL TESTING

Groundwater samples will be obtained prior to landfill development to establish baseline background water quality data for the landfill expansion site. Following refuse placement, samples will be obtained quarterly and analyzed for the following parameters:

- temperature
- pH
- specific conductance
- chemical oxygen demand (COD)
- volatile organic compounds (VOC's)
- dissolved chloride
- dissolved iron
- dissolved manganese
- sodium
- total Kjeldahl nitrogen

In addition to the above parameters, one sampling round per year will be analyzed for the following parameters:

- arsenic
- barium
- cadmium
- chromium
- lead
- mercury
- selenium
- silver
- sulfate
- total phenols
- nitrates

Groundwater quality laboratory results will be reported to State regulatory officials by Sanco personnel.

7.50 POST-CLOSURE GROUNDWATER MONITORING

Following landfill closure, the quarterly groundwater quality monitoring program will continue in accordance with the groundwater monitoring program discussed in Section 7.40. Groundwater quality monitoring data will be evaluated periodically with State regulatory personnel so that modifications to the frequency and parameters of the sampling and analysis program may be implemented consistent with observed groundwater quality conditions at the site.

TABLES

TABLE 1

SUMMARY OF GROUNDWATER LEVEL OBSERVATIONS

WELL No.	REFERENCE ELEVATION	SCREENED INTERVAL ELEVATION	GROUNDWATER ELEVATION					
			9/17/84	2/4/86	6/5/86	10/28/86	1/23/87	2/12/87
B-101	1350.8	1288-1308	1302.4	1298.9	1298.6	1298.3	1298.2	1298.0
B-102	1335.0	1272-1292	1304.4	1302.2	1301.4	1301.2	1300.9	1301.0
B-102S	1338.2	1297-1312					1300.0	1299.8
B-103	1335.6	1285-1295	1302.3	1299.4	1298.7	1298.6	1298.3	1298.2
B-103D	1335.4	1273-1288					1297.5	1297.3
B-104	1330.1	1293-1303	1310.8	1307.4	1307.3	1307.0	1306.8	1306.7
B-201	1343.9	1296-1316 (?)		1309.2			1308.5	1308.5
B-202S	1325.6	1303-1308		1308.8			1308.1	1307.9
D-202D	1325.9	1240-1242		1309.0			1308.5	1308.3
B-203	1336.9	1292-1312 (?)		1307.3			-	1307.4
B-204S	1332.5	1305-1310		1306.9			1306.8	-
B-204D	1333.3	1280-1282		1303.4			1288.4	1288.5
B-205	1325.8	1287-1307 (?)		1302.3			1302.1	1301.3
B-206	1319.1	1302-1322 (?)		1309.3			1307.9	1307.7
B-301S	1321.8	1289-1299					1293.5	1296.0
B-301M	1321.8	1276-1278					1295.1	1294.7
B-301D	1321.8	1233-1238					1301.5	1301.6
B-302S	1347.7	1296-1306					1303.9	1303.7
B-302D	1347.7	1249-1252					1292.4	1291.9
B-303S	1350.8	1291-1301					1299.0	1298.9
B-303D	1350.8	1253-1255					1289.4	1289.1
B-304S	1338.0	1284-1294					1285.7	1285.4
B-304D	1338.0	1259-1261					1284.9	1284.5
B-305S	1339.3	1300-1310					1304.7	1304.5
B-305D	1339.3	1257-1259					1258.7	1301.9
B-306S	1376.3	1304-1314					1307.9	1307.5
B-306D	1376.3	1268-1270					1307.6	1307.7
B-307S	1354.3	1302-1312					1308.9	1308.7
B-307D	1354.3	1271-1273					1273.6	1308.7
D-308S	1349.2	1303-1313					1311.7	1309.9
B-308D	1349.2	1281-1286					1312.2	1312.0

Notes:
1. Refer to the exploration location plan for observation well, monitoring well, and piezometer locations.
2. Elevations and locations of observation wells, monitoring wells, and piezometers were surveyed by Moose Brook Land Management. Elevations and locations should be considered accurate to the degree implied by the measuring method used.
3. Reference elevations refer to the elevation of the top of protective casing where present, or the top of PVC pipe.
4. Fluctuations in the level of the groundwater may occur due to factors other than those present at the time the measurements were made.

TABLE 2

SUMMARY OF TOTAL VOLATILE ORGANIC COMPOUNDS

IN SURFACE WATER AND GROUNDWATER

SAMPLE LOCATION	TOTAL VOLATILE ORGANIC COMPOUNDS (ppb)								
	9/17/84	9/27/84	2/15/85	6/24/85	9/13/85	2/6/86	2/26/86	6/12/86	11/25/86
B-101	10	31	6	trace	9		ND	trace	trace
B-102	2440	590	920	280	370		151	240	1105
B-103	26	337	934	744	506		179	74	127 (113)
B-104	trace	ND	trace	trace	ND		ND	ND	ND
Seep	trace		403	410	230		43	363	ND
B-201						ND			
B-202D						ND			
B-205						ND			

Notes:
1. Concentrations are in parts per billion (ppb).
2. ND indicates VOC's were not detected.
3. (113) indicates duplicate sample.
4. Laboratory testing was performed by Resource Analysts, Inc. of Hampton Falls, New Hampshire in general accordance with EPA Method 624.
5. Refer to Appendix C for laboratory data sheets.

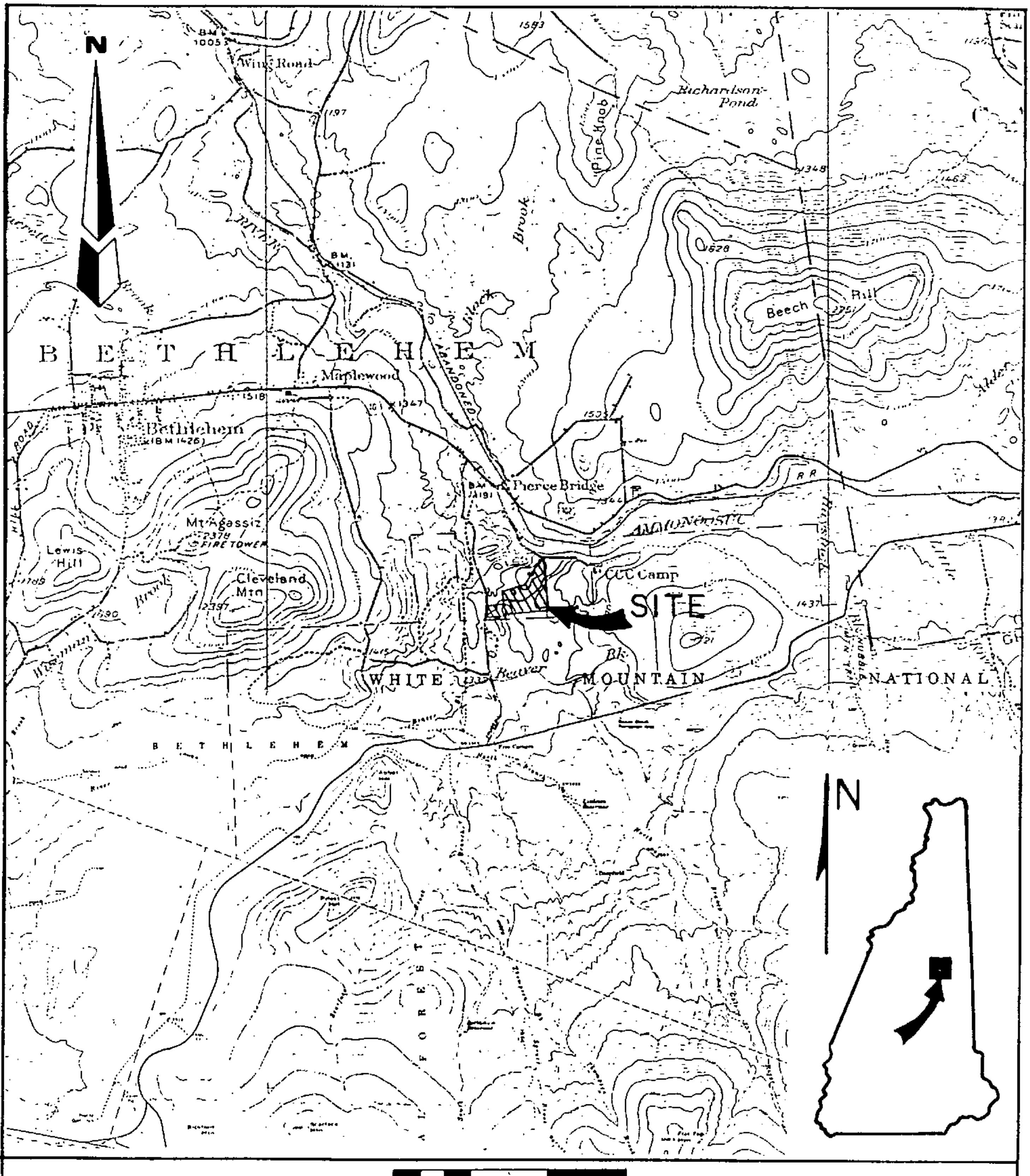
TABLE 3

SUMMARY OF HYDRAULIC CONDUCTIVITY CALCULATIONS

SAMPLE	DEPTH (feet)	LABORATORY SAMPLE DESCRIPTION	STRATIGRAPHIC UNIT	HYDRAULIC CONDUCTIVITY			
				BOREHOLE TEST ft/day	(cm/sec)	KOZENY-CARMAN ESTIMATE ft/day	(cm/sec)
B-302, S-12	60-61	Fine to coarse SAND, little Silt, trace Gravel	STRATIFIED DRIFT	0.18	(6.3×10^{-5})	0.5	(2×10^{-4})
B-302, S-16	95.3-96.6	Fine to medium SAND, little Silt	LOWER GLACIAL TILL			0.06	(2×10^{-5})
B-304, S-7	40-41.5	Fine to medium SAND, little Silt, trace Gravel	STRATIFIED DRIFT			0.4	(1×10^{-4})
B-306, S-12	75-76	Fine to coarse SAND, trace Silt, trace Gravel	STRATIFIED DRIFT	0.22	(7.7×10^{-5})		
B-307, S-10	45-46.5	Fine to medium SAND, little Silt, trace Gravel	STRATIFIED DRIFT	0.078	(2.7×10^{-5})	1	(3×10^{-4})
B-307, S-14	80-81.5	Fine to medium SAND, little Silt, trace Gravel	LOWER GLACIAL TILL	9.2	(3.2×10^{-3})	0.5	(2×10^{-4})
P-4, S-20	38-40	Fine to medium SAND, some (-) Silt, trace Gravel	UPPER GLACIAL TILL	1.5	(5.3×10^{-4})		
B-301, S-8	41.7-42.2	Fine to coarse SAND and Gravel, trace Silt	STRATIFIED DRIFT	31	(1.1×10^{-2})	26	(9×10^{-3})
B-301, S-9	50-50.6	Fine to coarse SAND, some Gravel, trace Silt	STRATIFIED DRIFT			24	(8×10^{-3})
B-304, S-12	65-65.3	GRAVEL and fine to coarse Sand, little Silt	LOWER GLACIAL TILL			0.06	(2×10^{-5})
B-305, S-9	40-41.5	SILT and fine to coarse Sand, trace Gravel	UPPER GLACIAL TILL	1.4	(4.9×10^{-4})		
B-303, S-13	75-76	Clayey SILT	STRATIFIED DRIFT	0.23	(8.2×10^{-5})		

Notes: 1. Refer to Appendix G for hydraulic conductivity calculations, borehole permeability test procedures, and Kozeny-Carman analysis method.

FIGURES



0' 3000' 6000' 9000'

FROM USGS:
WHITEFIELD, N.H.-VT. (1935)
FRANCONIA, N.H. (1967)
SOUTH TWIN MTN., N.H. (1967)
QUADRANGLE MAP

GZA	SANCO LANDFILL EXPANSION BETHLEHEM, NEW HAMPSHIRE	LOCUS PLAN MARCH, 1987 FIGURE No. 1

FILE No. D-20002