Gartner
Lee
Associates Limited

Consulting
Engineering
Geologists and
Hydrogeologists

Toronto - Buttonville Airport ■ Markham, Ontario ■ L3P 3J9 ■ 416-477-8400
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HYDROGEOLOGICAL STUDY
FINAL REPORT
PROPOSED BURLINGTON LANDFILL
SITE EXPANSION

PROJECT NO: 78-92

SEPTEMBER, 1979

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September 26th, 1979

M. M. Dillon Limited,
50 Holly Street,
Toronto, Ontario.
M4P 2G5

Attention: Mr. W. F. Wells, P.Eng.,
Project Manager.

Dear Sirs:

Re: Hydrogeological Study Report
Proposed Burlington Landfill Site Expansion
GLAL 78-92

We respectfully submit the hydrogeological study report for the above noted project, as requested.

The study involves a hydrogeological assessment of the lands immediately northwest of the existing landfill site and provides guidelines for development of these lands for a landfill. An intregal part of the study is the assessment of the existing site and its hydrogeological relationship to the proposed operation.

In summary, the lands may be developed for a landfill operation. The site design should include leachate collection and provide for a contingency interceptor drain along the toe of the Falcon Creek valley wall. As well, a toe drain should be installed on the west side of the Phase 1, expansion. These systems will assist in the control of leachate movement.

continued -

A summary of the report is contained in the first section and includes the conclusions and recommendations of the study. Detailed site descriptions and a discussion of hydrogeological considerations follow. Technical data is appended. The study is presented in the Metric System of Measurement.

We thank you for the opportunity to be of service and if there are any questions please feel free to call.

Yours very truly,

GARTNER LEE ASSOCIATES LIMITED

Grant Anderson

E. G. Anderson, P.Eng.,
Consulting Hydrogeologist

EGA/sv

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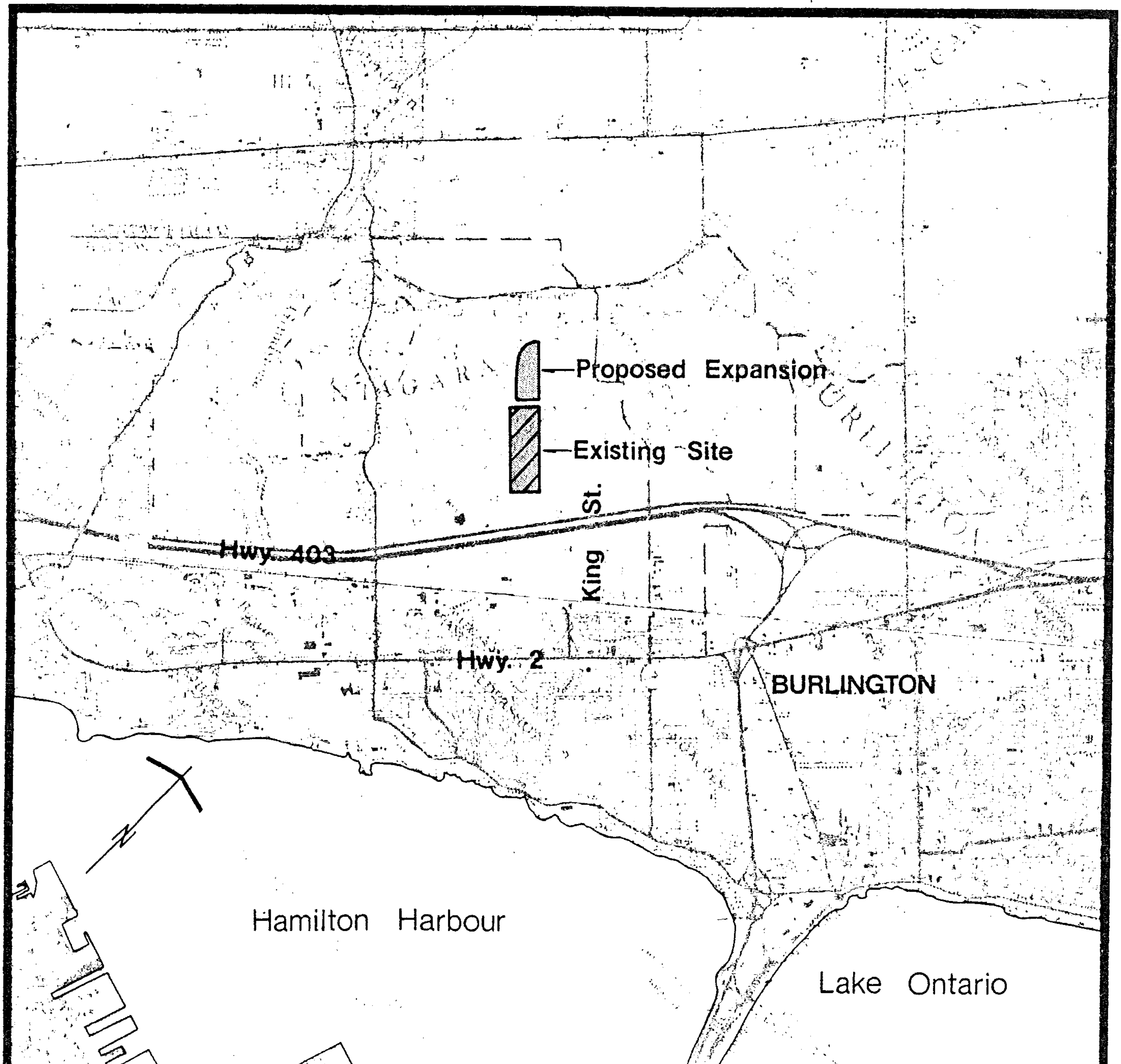


Key Map

Project 78·92
Scale 1:50,000

1.0 SUMMARY:

1.1 PURPOSE:

The principal objectives of this hydrogeological investigation are:

- to assess the hydrogeological setting of the existing landfill site and the lands proposed for expansion;
- to provide adequate hydrogeological data to establish the suitability of the proposed lands for solid waste disposal;
- to provide a basis for the Environmental Assessment Board to found part of its decision, for approval;
- to provide hydrogeological data for the design and operation of the proposed landfill;
- to establish guidelines for a ground and surface water quality monitoring programme.

1.2 SCOPE:

The study involves a detailed hydrogeologic assessment of the existing site and the proposed expansion area to the northwest. Data obtained provides a basis to predict the impact of the additional lands, on the environment. The study also provides hydrogeological criteria for the design and operation of the site. Thus the hydrogeological investigation encompasses both the environmental considerations and the design details.

1.3 HYDROGEOLOGICAL SETTING:

The hydrogeological and hydrological setting of the existing site and the proposed expansion is summarized below:

- The proposed expansion area at the Burlington Landfill Site is situated on the lower slopes of the Niagara Escarpment and is composed of glacial till soils over Queenston Shale bedrock. The Falcon Creek valley, eroded into the shale bedrock, borders the north and west limits of the proposed site.

- Ground water recharges within the proposed expansion area and flows towards the Falcon Creek valley. There is a minor component of flow south-easterly under the existing site. Data obtained during the early spring indicates that the principal flow direction in the shale was south-easterly which suggests at least a seasonal variation in the flow system.

- The natural quality of the ground water in the shale is relatively poor and may locally not comply with Ministry of the Environment guidelines for drinking water. There is no recorded ground water use within the area.

- A surface drainage divide bisects the proposed expansion area between the Indian Creek and Falcon Creek watersheds.

- The existing facility is located in the Falcon Creek Basin, south and down-gradient from the proposed expansion area. Leachate produced at the site infiltrates into the underlying shale. Migration is then principally downward and south-easterly with minor components of flow towards the west and east. A small portion of the leachate egresses as springs and enters the surface waters.

1.4 CONCLUSIONS:

The following conclusions are based on the results of this study:

- The proposed expansion area may be developed for solid waste disposal provided the facility is properly engineered and operated to minimize the impact of leachate on the ground and surface waters.

- An underdrain system is necessary to collect leachate and a toe-drain system along the west side of the Phase 1 expansion area. As well, there should be contingency plans for an interceptor drain on the east side of the Falcon Creek valley.

- Any contaminant migration from the proposed site would be principally towards the Falcon Creek valley, although seasonally migration may be under the existing site.

- There are no significant operational constraints from a hydrogeological viewpoint on the proposed facility.

1.5 RECOMMENDATIONS:

The following recommendations are based on the study findings:

- *A landfill may be developed on the lands northwest of the existing site and as described in this report.*

- *Adequate set backs from the brow of the valley should be incorporated into the design and no waste should be placed north of the ground water divide.*

- *A leachate collection underdrain system should be installed and designed to handle anticipated operational flows of 5.7 litres per minute per hectare. The recommended underdrain spacing is 45 m.*

- *A toe-drain system should be installed on the west side of the Phase 1 expansion area. Contingency plans for an interceptor drain within the Falcon Creek valley to collect leachate should be considered.*

- *A ground and surface water monitoring programme is required.*

2.0 INTRODUCTION:

The report describes the background to the project and the procedures and techniques employed to complete the study.

2.1 BACKGROUND:

A detailed hydrogeological study of the Burlington Landfill Site was recommended in the report 'Interim Waste Disposal Feasibility Study', dated September, 1978. On September 25th, 1978 written authorization was received from M. M. Dillon Limited to proceed with the study. The field work was subsequently delayed until access onto the lands could be obtained. Written permission to enter onto the lands was received on December 19th, 1978.

The hydrogeology at the Burlington Landfill Site including the abandoned Bayview Park Landfill was initially reviewed by Gartner Lee Associates Limited as part of the regional waste management study. Subsequently a more detailed reconnaissance evaluation was undertaken to specifically assess the feasibility of development of these lands. These results were incorporated into the 'Interim Waste Disposal Feasibility Study'. The present study examines the Burlington Landfill Site and the lands immediately to the northwest in detail, i.e. sub-surface investigations, ground and surface water monitoring and reporting. The results of the preliminary reconnaissance studies are incorporated where applicable.

2.2 METHODOLOGY:

A total of thirteen boreholes were placed at the locations shown on Plate 1, 'Site Plan', with a track-mounted mobile drill during the last half of January, 1979. Borehole depths varied between 9.2 m and 18.3 m. The overburden was sampled at regular intervals using standard split-spoon techniques and the standard penetration resistance measured at each sampling location. Rock core was retrieved at selected locations for geological logging and visual examination. Otherwise the rock was augered. Borehole logs are included in Appendix A.

Pressure packer tests, which measure the in-situ permeability were carried out at selected borehole locations. On completion of each borehole, piezometers which measure the hydrostatic water pressure at a point and a standpipe which measures the ground water table were installed. These monitors were developed by pumping and water level readings taken over the following months. The conductivity of the ground water was measured periodically and representative water samples retrieved for chemical analysis by the Ministry of the Environment's laboratory. Slug tests, which is another technique for assessing the in-situ permeability using the piezometer installations, were completed. All pertinent data are recorded in the Appendices.

Surface waters were also monitored during the study period. Four stations, see Plate 1, for locations, were established. Stream flow was estimated using a pail and stop-watch technique. Water quality was assessed through field conductivities and laboratory testing.

Three test pits were excavated (Plate 1) on June 11th, 1979 with a hydraulic backhoe. A visual examination of the pits provided data on the geologic stratigraphy, ground water conditions, soil characteristics as related to diggability, workability and handling, and fracture patterns. Fracture widths were also gauged for use in fracture flow analysis. See Appendix A for the test pit logs.

The Regional Municipality of Halton provided both vertical and horizontal survey control for the boreholes and monitors.

Representative soil samples were laboratory tested to determine the grain size distribution, the Atterberg limits and the cation exchange capacity. The permeability of a relatively undisturbed sample of the glacial till was determined using the constant head permeameter technique. As well, the in-situ moisture of all soil samples was measured. See Appendix A for the results.

Once all data had been collated, the analysis was completed, and the hydrogeological report prepared to document the study findings and to present the conclusions and recommendations.

3.0 STUDY RESULTS:

This section of the report describes the hydrogeological and hydrological setting of the Burlington Landfill Site and the proposed expansion area. The results are supported by the technical data contained in the Appendices and are supplemented by a series of plates.

3.1 PHYSICAL SETTING:

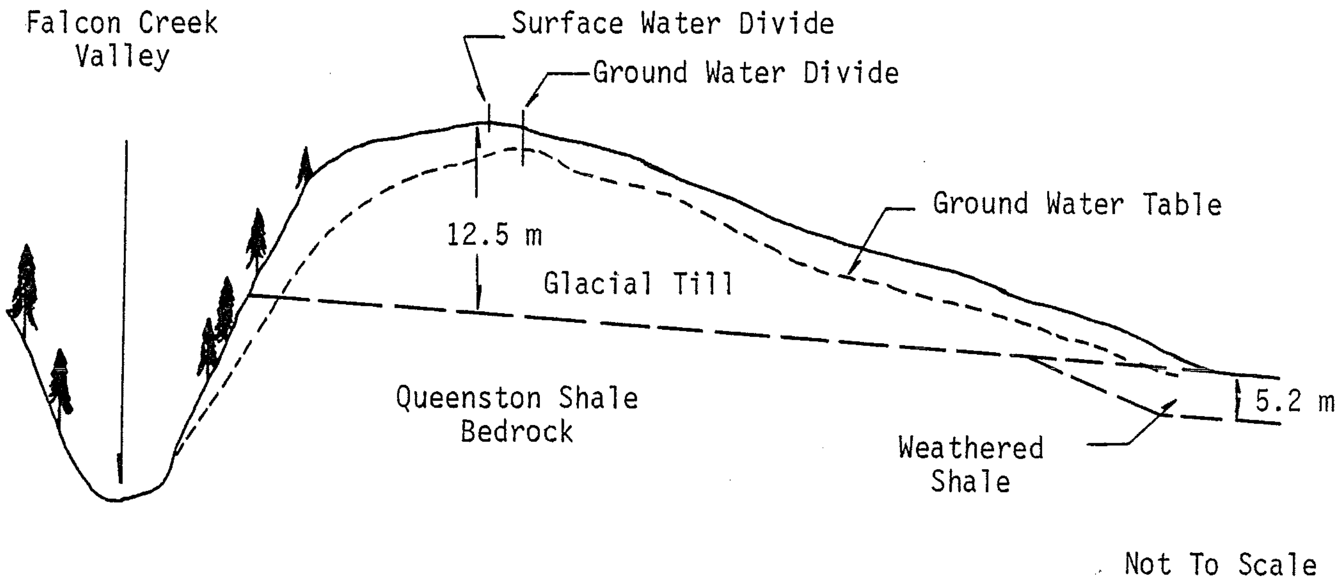
Regionally the subject lands are situated on the lower slopes of the Niagara Escarpment in an area heavily dissected by gullies and ravines. The upper portions of the slopes are covered by a considerable thickness of glacial drift. However, the drift thins to the south where bedrock exposures predominate. The former shoreline of postglacial Lake Iroquois is just south of Highway 403. The deeper ravines usually are associated with prominent water courses and are eroded into the shale bedrock. See the Key Map for the geographic location of the site.

The lands comprising the site slope moderately towards the south and east, except as altered by the existing fills. As shown on Plate 2, 'Physical Setting', the proposed expansion area is covered by glacial till ranging in depth from 12.5 m in the north to virtually absent in the southern corner. The original soils under the landfill appear to be quite thin and may be locally absent. A deep ravine, eroded into the shale bedrock borders the western periphery of the site. Adjacent to the proposed expansion area the valley walls are wooded. However, to the south, vegetation is sparse and the soft shale rock is susceptible to erosion. Presently, numerous small gullies are evident. A less pronounced ravine borders the east side of the expansion area. The bedrock surface, as shown on Plate 3, 'Bedrock Topography', slopes south-easterly at an average of about 5%.

The existing landfill occupies the southern end of the study area. The waste, which is probably deposited directly onto the undisturbed ground, appears to be in the order of 5 to 13 m deep. There are no significant earth berms around the waste, although there is some minor earth work east and north of the landfill entrance. A leachate collection, toe-drain system is proposed, but was not constructed at the time of the present study. Leachate springs, see Plate 2, 'Physical Setting', are common along the southern perimeter of the waste and to a lesser extent along the eastern and western perimeter. The frequency of the springs decreased in a northerly direction. Most of the springs were located near the toe of the waste. However, some springs within the landfill itself were noted and may be associated with a perched leachate condition related to the slowly permeable daily soil cover. Field observations indicate that the majority of the springs cease flowing during periods of dry weather.

3.2 GEOLOGIC DETAILS:

The sequence of geologic materials encountered within the proposed expansion area is shown schematically in Sketch 1. Three scaled geologic cross-sections have been prepared and are contained in Appendix A.



SKETCH 1

3.2.1. GLACIAL TILL:

The proposed expansion area is mantled by a relatively dense to very dense clayey silt till from a maximum depth of 12.5 m within the northern section to 0 to 2.4 m within the southern section. Till was not encountered within the study area, south of the proposed expansion lands. No sand seams or pockets were intersected in either the boreholes or the test pits.

It appears that the glacial till is fractured, possibly the result of dessication and/or stress relief throughout its post-glacial history. These fractures were noted to extend to 6.4 m (bottom of deepest test pit) in the deeper drift to the north and to the rock in the shallower drift to the south. Based on observations in the test pits, the fractures are tight, generally less than .08 mm in size, are discontinuous and are randomly spaced. Occasional fractures up to 1 mm in size were noted.

Laboratory tests were undertaken to measure the physical properties of the glacial till. As shown on Figure 1, Appendix A, the grain size of the till, based on the M.I.T. Classification System, is distributed as follows:

Gravel	(>2 mm)	1 - 6%
Sand	(2-.06 mm)	4 - 15%
Silt	(.06-.002 mm)	40 - 54%
Clay	(< .002 mm)	36 - 44%

Based on the Atterberg Limit tests, the liquid limit averages 33% and the plasticity limit averages 14%. The in-situ moisture of the soil at the time of the field work was generally less than the plastic limit. This relationship depends on climatic conditions, in part, and will change accordingly. The cation exchange capacity of the till averages 10.5 milliequivalents per 100 gm of soil. The bulking factor for the till is about 15%, depending on the compactive effort employed.

The intrinsic permeability of the glacial till, based on both field and laboratory testing and empirical relationships, is in the order of 10^{-7} cm per second, or about .03 m per year. However, within the fracture zone of the till, the permeability will be considerably higher. The fracture permeability is estimated at about 3 m per year.

The porosity of the till is in the order of 30%. However, where fracture flow governs, the porosity becomes about 5%.

Results of the test pits indicate that the material is diggable with a hydraulic backhoe, though due to the relative density excavation is probably not practical with earth scrapers. However, it is recommended that a contractor be consulted, or alternatively a field trial be completed with an earth scraper to accurately assess the equipment's capability.

The till has good workability characteristics at its in-situ moisture, but may become 'sticky' when wet. Ground water infiltration into the test pits was unmeasurable from the till horizon, even though the pits were excavated below the water table. Any ground water infiltration is associated with the rock as in Test Pit 3.

3.2.2. SHALE:

The bedrock which underlies the entire study area is the Queenston Formation of Ordovician Age, and is commonly referred to as 'Queenston Shale'. The Queenston Formation is in the order of 180 m thick.

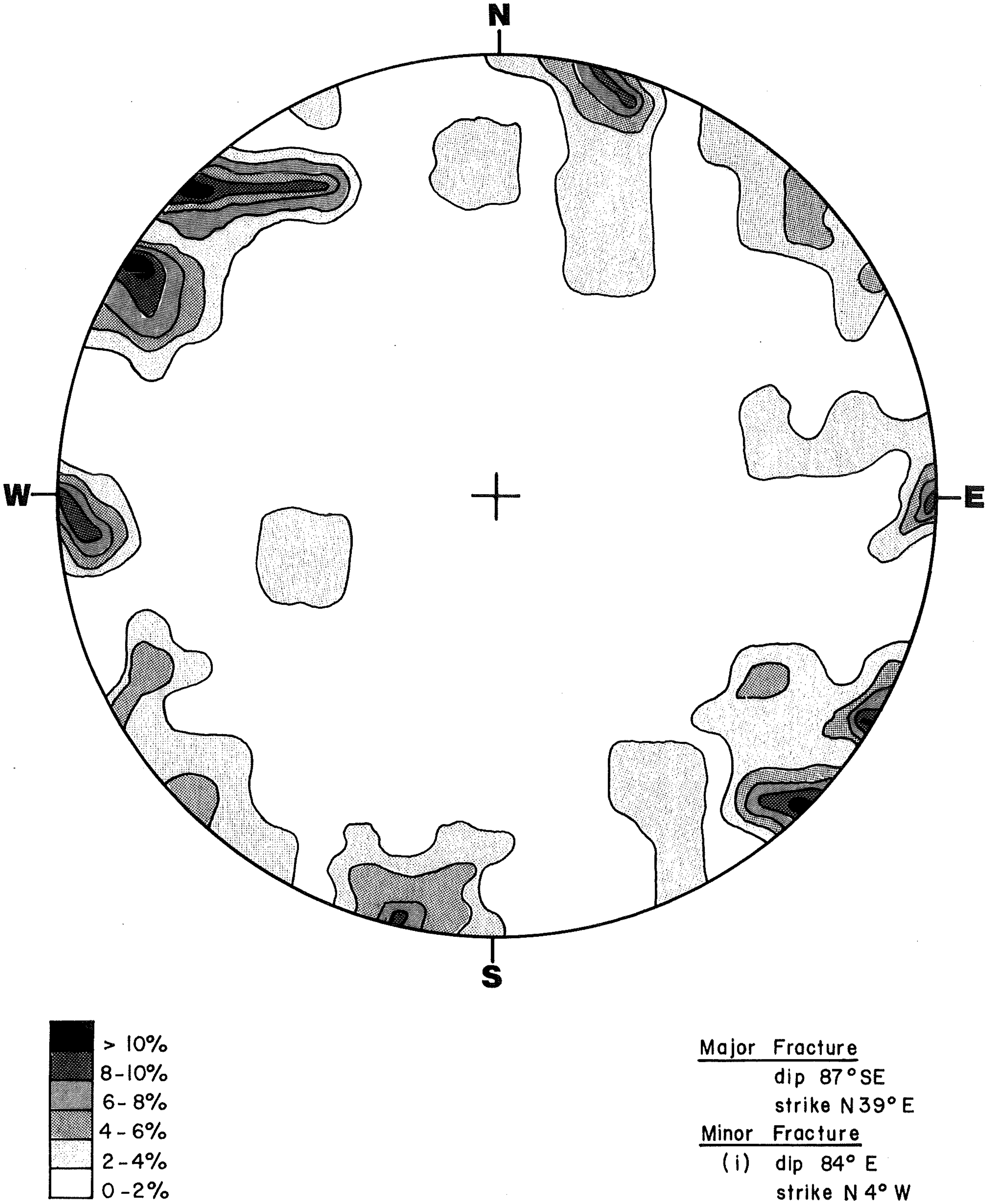
The shale is reddish brown in colour with random bands of greenish grey. It is cryptocrystalline in texture and is generally massive to thick bedded. Locally the bedding may become thinner. The greenish grey bands are harder and more brittle. These zones are probably more permeable as evidenced by seepage along these beds.

The shale bedrock is fractured and jointed. A stereogram analysis of the joint pattern indicates that the major axis of orientation has an average bearing of north 39° east and a minor axis bearing about north 4° west. See Figure 2 on the following page. Measurements were made of the fracture size in the test pits. The fractures are predominantly tight, less than .08 mm in size, although some fractures up to .4 mm were noted. No reported pattern of fracture size was noted.

The permeability of the shale, as measured in the field from pressure packer tests and slug tests, is estimated at about 5×10^{-6} cm per second, or 1.6 m per year. As shown on Table 4, Appendix A, individual test results varied from a low of 7×10^{-7} cm per second to a high of 2×10^{-5} cm per second. There are no apparent trends of either increasing or decreasing permeability with depth based on the test results. However, the literature generally sites a decreasing permeability with depth in this type of shale rock. Additional field work in deep borings would be required to establish any trends at this site.

The porosity of the shale is estimated to be 5%, which is the median value of the range generally quoted for this rock type.

BURLINGTON LANDFILL CONTOURED JOINT SCATTER DIAGRAM QUEENSTON FORMATION



Major Fracture
dip 87°SE
strike N39°E

Minor Fracture
(i) dip 84° E
strike N 4° W
(ii) dip 86° SSW
strike S64°E
(w.r.f. true north)

FIGURE 2

3.2.3. WEATHERED SHALE:

The upper surface of the Queenston Formation may be weathered, particularly where exposed to the atmosphere. The depth of weathering is variable from non-existent at many borehole locations to a maximum of 5.2 m at Borehole 5. See the borehole logs and cross-sections in Appendix A.

The weathered shale, although variable in physical condition depending on the degree of weathering, is generally fairly soft and broken into small sub-angular blocky chunks. Fracture patterns are usually not evident due to the irregular broken condition of the shale.

3.2.4. REFUSE:

The refuse was not extensively investigated, but is comprised of domestic, commercial, industrial, construction and demolition wastes. Landfill wastes of this type have a permeability in the order of 10^{-3}cm per second (315 m per year) and a porosity of about 25%.

3.3 GROUND WATER MOVEMENT:

The ground water table configuration over the study area is shown on Plate 4, 'Ground Water Regime - Water Table'. Generally the pattern is a subtle reflection of the surface topography. The water table slopes predominantly to the southeast with components towards the Falcon Creek valley. The surface of the water table within the proposed expansion area is in the glacial till and varies in depth from near ground surface in the uplands to about 3.5 m near the top of the valley wall. The valley tends to draw the water table down. Within the refuse, the true water table is well below ground surface. Indications are that only the lower 1 to 2 m of the refuse is below the water table and in fact in some areas, reference Plate 11, 'Ground Water Section C-C'', the waste is above the water table. The water levels will fluctuate from those measured during the study period, according to climatic conditions.

The pattern of the potentiometric surface as measured in the shale bedrock is shown on Plate 5, 'Ground Water Regime-Bedrock'. Within the expansion area ground water flow is towards the Falcon Creek valley, while flow under the existing site is predominantly southeast.

Ground water gradients, measured during the study period, indicate that the site is within a ground water recharge zone, i.e. the gradients are downward. Thus ground water flows downward through the glacial till and shale bedrock and is gradually deflected as shown on Plate 5. Locally the gradients are very steep and indicate strong recharge. The Falcon Creek valley is a ground water discharge zone. The ground water cross-sections, Plates 9, 10 and 11, show the ground water flow in June, 1979.

Ground water flows according to the relationship

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

Where: V = velocity
k = hydraulic conductivity (permeability)
i = hydraulic gradient
n = porosity

This relationship is a form of Darcy's Law and has been modified by the Dupuis-Forchheimer Assumption. Based on this relationship, ground water flows in the till, assuming intrinsic soil properties at a rate typified by Borehole 1. If the hydraulic conductivity is .03 m per year, the hydraulic gradient is 0.2 m per metre and the porosity is 30%, then the velocity in the vertical direction is 0.02 metres per year. However, if fracture flow occurs, the ground water velocity would increase to about 14 m per year, at Borehole 1.

Ground water flows in the shale along joints, fractures and bedding planes. Thus the velocity is dependent on the size of the openings and will vary considerably throughout the rock mass. The velocity was calculated using both the Darcy relationship and fracture flow formula. Results indicate that a typical flow velocity is in the order of 20 m per year but varies considerably, as discussed above.

3.4 GROUND WATER QUALITY:

A geochemical monitoring programme was established on completion of the field drilling programme. Results to date are presented in Appendix B. As well, three cross-sections have been prepared to show the ground water chemistry on field conductivities in June, 1979. The plates, numbers 12, 13 and 14, are contained in Appendix B.

The background or natural water quality within the shale bedrock as observed up-gradient from the landfill, is relatively poor and at least locally does not comply with the Ministry of the Environment's guidelines for drinking water. Results of the field and laboratory testing indicate that the conductivity of the ground water is naturally high and parameters such as sulphates, hardness, sodium and iron are present in excessively high concentrations. There appears to be a tendency for a degradation of water quality with depth. However, water quality will vary locally depending on the hydraulic connection within the shale itself. Normally the better the hydraulic connection, the faster the ground water travels and the better the water quality.

The leachate, as observed in the standpipe in Borehole 8 (see Table 8, Sheet 3), contains a high concentration of chemical parameters and is moderately acidic. The water chemistry in the deep piezometer located in Borehole 8 in the shale beneath the landfill indicates that the leachate has migrated to depth as the parameters tested have a higher concentration than the background levels. Based on ground water flow patterns the leachate plume should extend downwards and south of the landfill. There should also be an upper horizon of relatively uncontaminated water immediately down-gradient of the fill. The geochemical results in the upper piezometer in Borehole 12, located down-gradient from the landfill show that the water chemistry is typical of the background and thus confirms the presence of an upper zone of relatively uncontaminated water. Conductivity is increasing with depth.

3.5 GROUND WATER USE:

There is no recorded ground water use in the immediate vicinity of the existing or proposed facility. The lands to the east are vacant and Highway 403 crosses south of the site. The property immediately south of Highway 403 is presently undeveloped to the Canadian National Railway corridor. Any development to the west and north is across the Falcon Creek valley which is a hydrogeologic boundary condition.

3.6 HYDROLOGIC SETTING:

3.6.1. WATERSHED:

The existing Burlington Landfill Site and the proposed expansion are situated within the Falcon Creek and Indian Creek watersheds. Within the proposed expansion area, about 3.5 hectares are in the Falcon Creek basin, while about 6 hectares are in the Indian Creek basin. The existing fill is in the Falcon Creek basin.

The Falcon Creek basin encompasses a total of about 400 hectares and is drained by Falcon Creek and its tributaries. The head waters are situated in the lands above the Niagara Escarpment, although some tributaries appear to be spring fed from the Escarpment itself. The creek has eroded a deep ravine along the western and northern periphery of the site as it flows through the lower escarpment lands towards Lake Ontario. The creek channel is about 7 km in length, and the average gradient from the Escarpment to Lake Ontario is about 2.5%.

There are no gauging stations on Falcon Creek to measure flow. However, measurements were taken during the course of the study to approximate the flow. In April and the early part of May, the flow varied between 800 and 900 litres per minute. The flow doubled in May subsequent to heavy rains but has decreased with the advent of the drier summer months. By mid-July, there was no flow at the monitoring stations.

Geochemical analysis of water samples taken above and below the landfill indicates a slight deterioration of water quality down-gradient. The degree of contamination may vary seasonally. Chemical laboratory analysis of water samples taken near Highway 403, down-gradient from the landfill site, indicate that most chemical parameters are within an acceptable range.

The Indian Creek basin is approximately 590 hectares in size. The head waters of the creek and its tributaries are located along the Niagara Escarpment, possibly fed by springs, and on the lower slopes. The Creek discharges into the Hamilton Harbour. There is no flow or water quality information available on the Creek.

3.6.2. WATER BUDGET:

A water budget was prepared for this site based on 20 year normal weather data obtained from the Burlington Climatological Station. The potential evapotranspiration was calculated using the Thornthwaite Method. Following is a summary of the results shown in Figure 3, 4 and 5, of Appendix C.

Average Annual Total Precipitation	76.1 cm
Average Annual Potential Evapotranspiration	62.5 cm
Potential Water Surplus	13.6 cm

In this area the actual evapotranspiration is about 10 cm less than the potential calculated by the Thornthwaite Method. Thus, the actual annual water surplus available for infiltration and run-off is about 23.5 cm on the average.

During the operation of the landfill, precipitation is lost through run-off and evaporation, and the remainder infiltrates. It is estimated that the infiltration rate may be about 30 cm per year or 5.7 litres per minute per hectare. Once the site is closed, final covered and vegetated, the infiltration rate should be around 10 cm per year or 1.9 litres per minute per hectare.

4.0 ASSESSMENT AND DEVELOPMENT:

The following paragraphs describe the hydrogeological and hydrological considerations for the expansion of the existing facility, and discuss the development and operational aspects. Guidelines for ground and surface water monitoring are also presented.

In summary, we conclude that a solid waste disposal facility may be developed on the lands described in this report. The site design should include a leachate collection underdrain system and provide for a toe drain along the west toe of the Phase 1 existing fill and for a contingency interceptor drain along the toe of the Falcon Creek valley wall. These systems will assist in the control of leachate movement.

4.1 WATER QUALITY ASPECTS:

4.1.1. GROUND WATER:

The existing landfill facility is generating leachate at an estimated rate of 5.7 litres per minute per hectare or about 100 litres per minute total volume. From mass balance calculations it is estimated that about 70% of this volume exfiltrates through the shale base and the remainder enters the surface waters through overland flow. Underflow calculations indicate that the rock has the capacity to accommodate these volumes of leachate even at a lower permeability then established through the field pressure packer and slug tests.

Once the leachate enters the ground water flow system, it travels downward with the strong recharge gradients and gradually deflects in a south-easterly direction. Thus a leachate plume is developed in the rock under the fill and down-gradient from the site. The upper ground water zone above the leachate plume down-gradient of the fill does not show any significant signs of contamination from the landfill.

Attenuation within the shale is probably restricted to dilution as the leachate mixes with ground water and dispersion as the leachate moves through the ground water flow system. Synthetic compounds such as phenols do not occur naturally and may be used as tracers. Ion exchange is probably limited since contact areas are small in the flow fractures within the rock, as compared to intergranular flow in soils.

There are no recorded ground water uses in the immediate vicinity. Consequently, contaminants which are generated at the existing facility and enter the ground water flow system, are not creating an interference problem at the present time. As well, the background water quality in the area is relatively poor and according to Ministry of the Environment guidelines may be, at least locally, undesirable for drinking.

At the proposed expanded facility, northwest of the present site, wastes will be placed on a minimum 1.5 m deep layer of glacial till. Ground water flow through the till may be very slow, in the order of 2 cm per year, and thus the till would provide a good buffer between the waste and the rock. However, the field work indicates that the till may be fractured and these fractures may extend to the rock particularly in the south portion of the expansion area. Ground water flow could be a thousand times greater in the fractured environment.

Leachate, generated at the proposed expansion, will eventually enter the ground water flow system within the shale and migrate either southeast under the existing site or towards Falcon Creek. Since the ground water under the existing site is already contaminated, the influx of additional contaminants from the expanded facility should have a minimal impact. The movement of contaminated ground water towards Falcon Creek is a concern, and will have to be controlled. See Section 4.2.2.

The glacial till has some potential for attenuation by ion/cation exchange mechanisms where intergranular flow governs. However, the attenuation capabilities decrease within the fractured flow system and are not considered a significant factor. Since at least a portion of the leachate will migrate from the site via fracture flow, attenuation by exchange mechanisms will probably be minimal.

4.1.2. SURFACE WATER:

Leachate from the existing facility is entering the surface drainage system and has had an impact on the quality of the water in Falcon Creek. A toe-drain system has been designed, but not currently installed, to control leachate springs around the periphery of the waste and thus protect the surface water environment.

At the proposed expanded facility, leachate springs can also be anticipated. These springs if not intersected, could potentially affect water quality in Falcon Creek. Also there is a potential for contaminants to enter the Indian Creek basin by surface flow which constitutes the eastern portion of the proposed expansion area.

The proposed expansion area is less than 1% of the total area of the Falcon Creek basin and about 1% of the total area of the Indian Creek basin. Thus, any affect on the water budget of the drainage basins as a result of the expansion may be considered minimal.

4.2 DEVELOPMENT ASPECTS:

4.2.1. GENERAL:

The proposed expansion area may be developed for both area fill and a trench type of operations. It is recommended that a minimum of 1.5 m of glacial till be retained between the waste and the rock. Where existing soil depths are insufficient, clay type fill material, compacted to 100% standard Proctor, should be placed to a total soil depth of 1.5 m, if these areas are to be landfilled.

We recommend that a minumum 10 m buffer be maintained between the top of the Falcon Creek valley wall and the waste. As well, no waste should be placed north of the ground water divide shown on Plate 5.

4.2.2. LEACHATE COLLECTION SYSTEMS:

As discussed in Section 4.1.1. of this report, leachate is expected to migrate away from the fill area. Although the impact on the existing water quality southeast under the present site is anticipated to be minimal, there is a concern with contaminated ground water flowing towards Falcon Creek.

We therefore, recommend that a leachate collection underdrain system be installed on the floor of the disposal site to reduce the exfiltration of leachate and to minimize ground water mounding in the waste. The system should be designed and constructed as suggested below:

- The system should operate by gravity drainage with flow in a southerly direction.
- The collector laterals should be perforated pipe of adequate strength to support the weight of the refuse.
- The collector laterals should be placed at a maximum 45 m spacing.
- Pipe sizing may be based on anticipated leachate volumes of 5.7 litres per minute per hectare.

- The collector laterals should be bedded in a graded filter or alternatively, wrapped with filter cloth, to minimize siltation.

- A minimum .3 m layer of porous material, having a permeability of not less than 10^{-3} cm per second (315 metres per year) should be placed on the cell floor, over the laterals.

In order to increase the efficiency of the system, consideration may be given to re-working the soils on the bottom of the landfill to seal any fractures. This work would involve a .6 m excavation below the bottom grade and re-compacting in .2 m lifts to 100% standard Proctor.

We also recommend that plans be prepared for the construction of a toe-drain along the west side of the waste in the Phase I expansion area to intercept any leachate springs.

Further a contingency plan should be considered to collect contaminated ground water at the toe of the Falcon Creek valley wall, if monitoring indicates a potential problem in the creek from ground water flow. An interceptor drain extending to the ground water divide shown on Plate 5, should be adequate.

4.3 OPERATIONAL ASPECTS:

The conditions at the proposed expansion area are generally favourable for a landfill operation. Some problems may be anticipated for excavation of the glacial till from a diggability viewpoint, if earth scrapers are used. The excavated material is suitable for both daily and final cover and can be used for general earth works around the site. However, wet weather handling may be a nuisance because of the clay content of the soil. Further details follow.

Excavation is generally feasible with hydraulic backhoe equipment. Some excavation difficulties may be experienced with the earth scrapers due to the very dense nature of the till. Poor traction is also a concern during wet weather. In this regard we suggest that a local contractor be consulted or a field test be completed to assess the capability of earth scrapers on this site. Very minor ground water seepage may be locally anticipated but not in quantities which would require special treatment. Cell walls should stand at near vertical under normal conditions. All bottoms and walls should be mapped for sand seams to determine the need for any special treatment prior to landfilling.

The excavated soil is suitable for daily and final cover. We would recommend .15 m of daily cover and between 1.0 to 1.5 m of final cover. The final cover should be vegetated to promote evapotranspiration and thus reduce infiltration and deter surface erosion.

Prior to landfilling, all boreholes, any gas or water wells and any other conduits for leachate movement should be properly sealed.

4.4 LANDFILL GASES:

Methane and carbon dioxide are the gases of principal concern which are generated at a sanitary landfill site. Carbon dioxide which is heavier than air mixes with the ground water. The mixing results in an increased ground water hardness. The methane, which is explosive in concentrations of 5 to 15% methane with air, is lighter than air and tends to migrate.

The hydrogeological conditions at the proposed expansion area are not generally conducive to methane migration off-site. Any gas will naturally tend to vent by upward movement. However, the slowly permeable till soils around the waste will retard lateral migration. The fractures within the upper till may allow some movement particularly under frost conditions, but this movement should not be a concern.

Initially no engineered venting system is required, since venting should occur naturally. Also conventional gas monitoring is not required at this time. However, if development encroaches the site monitoring for gas movement should be undertaken and the need for gas venting determined at that time.

4.5 GROUND WATER MONITORING:

An extensive ground water monitoring programme was established in connection with the present study. This monitoring programme has provided the background chemistry. However, we suggest that the programme be continued and expanded as follows:

- Ground water monitors around the periphery, i.e. Boreholes 1, 2, 3, 5, 6 and 7 should be protected during site development.
- Ground water levels should be recorded in all installations, monthly for one year.
- Ground water samples should be tested in the field for conductivity and pH, and samples submitted to a laboratory for phenol analysis once every three months. Phenols should be used initially as an indicator due to the high and often variable concentrations of other parameters.

- Proper and complete records should be prepared.
- All results should be reviewed and the monitoring programme re-assessed on an annual basis by an experienced hydrogeologist.

4.6 SURFACE WATER MONITORING:

We recommend that three surface water monitoring stations be established on Falcon Creek. Stations 1 and 2 may correspond to the observation points established for this study. A third station should be located up-gradient, beyond the limits of the proposed expansion fill area.

The stream flow should be measured at each station and the conductivity, pH and phenols analysed once every three months. As with the ground water monitoring programme, proper records should be kept and the results reviewed once a year by an experienced hydrogeologist. We suggest this programme be continued for initially a period of five years at which time it should be reviewed.

Report Prepared By

DEJagger

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Under the Supervision Of

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DEJ/sv

APPENDICES

5.0

APPENDIX `A´

GEOLOGIC DETAILS

LIST OF ABBREVIATIONS

PENETRATION RESISTANCE

Standard Penetration Resistance 'N' - The number of blows required to advance a standard split spoon sampler 30 cm into the subsoil, driven by means of a 63.5 kg hammer falling freely a distance of 75 cm.

Dynamic Penetration Resistance - The number of blows required to advance a 5 cm, 60 degree cone, fitted to the end of drill rods, 30 cm into the subsoil, the driving energy being 475 J per blow.

DESCRIPTION OF SOIL

The consistency of cohesive soils and the relative density or denseness of cohesionless soils are described as follows:

Consistency	'N' Blows / .3 m	Denseness	'N' Blows / .3 m
Very Soft	0-2	Very Loose	0-4
Soft	2-4	Loose	4-10
Firm	4-8	Compact	10-30
Stiff	8-15	Dense	30-50
Very Stiff	15-30	Very Dense	> 50
Hard	> 30		

W.T.P.L. - Wetter than Plastic Limit
D.T.P.L. - Drier than Plastic Limit
A.P.L. - About Plastic Limit

DESCRIPTION OF ROCK

$$\% \text{ Recovery} = \frac{\text{Total Length of Core Recovered/Run}}{\text{Total Length of Drilling Run}} \times 100$$

TYPE OF SAMPLE

SS	-	Split Spoon
AS	-	Auger Sample
ST	-	Shelby Tube Sample
NX	-	Rock Core 56 mm ø

SYMBOLS

▲	-	Water Table Monitor (Standpipe Tip)
●	-	Piezometer Tip
▼	-	Water Level
▽	-	Piezometric Head

BOREHOLE NO. 1

PROJECT NAME BURLINGTON LANDFILL SITE PROJECT NO. 78-92
CLIENT M.M. DILLON LIMITED DATE JANUARY 23, 1979
BOREHOLE TYPE BOMBADIER 0.1 m I.D. Hollow Stem Augers / NX Rock Core GEOLOGIST A.B.
ELEVATION 183.4 m TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/ 0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.2		TOPSOIL						
		TILL: Medium brown clayey silt till becoming grey brown at 9.1 m hard, A.P.L. Fractures to 6.4 m becoming W.T.P.L. at depth						
			SS	70	13			Sample 3.8-4.6 m 6% gravel 10% sand 48% silt 36% clay
			SS	33	17			
			SS	30				
			SS	60	11			
			SS	92				
12.5								
		SHALE: Red and green cryptocrystalline, massive bedded shale: weathered, with mud seams to 15.2 m						
			NX			70		
			NX			70		
			NX			100		
18.3		Borehole terminated at 18.3 m in shale						

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BOREHOLE NO. 2

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 16, 1979

BOREHOLE TYPE BOMBADIER, 0.1 m I.D. HOLLOW STEM AUGERS, NX ROCK CORE — GEOLOGIST A.B.

ELEVATION 171.2 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	BLOW/ 0.3 m	M/C	% RECOVERY	GROUND WATER	REMARKS
0.2		TOPSOIL						
		TILL: Red brown clayey silt till, D.T.P.L. hard, minor vertical fracturing to 4.6 m	SS	61	13			
			SS	65	7			
4.6		SHALE: Red with green bands and green mottling, cryptocrystalline massive to thick bedded shale soft, fracturing at an angle to the core, green bands are hard.	NX			100	▲	
			NX			100	●	
11.0		Borehole terminated at 11.0 m in shale						

● Piezometer Tip ▲ Standpipe Tip

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BOREHOLE NO. 3

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 19,22, 1979

BOREHOLE TYPE BOMBADIER 0.1 m I.D. HOLLOW STEM AUGERS, NX ROCK CORE — GEOLOGIST A.P.

ELEVATION 167.6 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/ 0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.2		TOPSOIL						
2.4		TILL: Medium brown clayey silt till, hard, A.P.L. horizontal fracturing	SS	71	15			
4.0		WEATHERED SHALE: Red brown shale hard, DTPL	SS	121	9			
10.7		SHALE: Red with green beds and soft mud seams to 7.0 m, weathered. Green shale from 7.0 m to 10.7 m with minor red mottling; shale is cryptocrystalline, massive bedded throughout	NX			100		
			NX			100		
		Borehole terminated at 10.7 m in shale						

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BOREHOLE NO. 4

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 15, 1979

BOREHOLE TYPE BOMBADIER 0.1 m I.D. HOLLOW STEM AUGERS, ROCK CORE — GEOLOGIST A.B.

ELEVATION 174.2 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.2		TOPSOIL						
		TILL: Clayey silt till changing from mottled red-brown to grey with depth, hard, minor vertical fracturing to 4.9 m seepage at 4.0 m D.T.P.L.	SS	24	14			
			SS	63	13			
			SS	80	13			
			SS	>100	12			
			SS	75	14			
			SS	52	14			
			SS	65	13			
7.8		SHALE: Red, with green bands and green mottling, crypto-crystalline, massive to thick bedded shale, soft, fracturing at an angle to the core, green bands are hard	NX			100	▲	
			NX			100		
14.0							●	
		Borehole terminated at 14.0 m in shale						

● Piezometer Tip ▲ Standpipe Tip

Gartner Lee Associates Limited

BOREHOLE NO. 5

PROJECT NAME BURLINGTON LANDFILL SITE | PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED | DATE JANUARY 18, 1979

BOREHOLE TYPE BOMBADIER, 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE | GEOLOGIST A.B.

ELEVATION 164.7 m. | TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/ 0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.1		TOPSOIL:						
		WEATHERED SHALE: Red brown weathered shale - minor green mottling, moist very stiff to hard, seepage at 3.0 m.	SS	23	13			
			SS	68	10			
			NX			85		
5.2		SHALE: Red with green bands and green mottling, cryptocrystalline variable bedded shale, thin bedded and weathered to 6.4 m high green shale content	NX			100		
			NX			100		
12.2		Borehole terminated at 12.2 m in shale						

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BOREHOLE NO. 6

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 17, 1979

BOREHOLE TYPE BOMBADIER 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE — GEOLOGIST A.B.

ELEVATION 173.7 — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	BLOW/ 0.3 m	M/C	% RECOVERY	GROUND WATER	REMARKS
0.2		TOPSOIL						
		TILL: Medium brown clayey silt till, D.T.P.L. hard, fractures to 2.0 m seepage at 3.4 m becoming grey brown at 6.1 m						
			SS	89	10			
			SS	81	9			
			SS	60	13			
			SS	47	15			Sample #4 1% gravel 8% sand 47% silt 44% clay
7.8		SHALE: Red, with green bands and green mottling, cryptocrystalline, massive to thick bedded shale minor fracturing at an angle to the core	NX			100		
							▲	
			NX			100		
			NX			100		
							●	
16.9		Borehole terminated at 16.9 m in shale						

▲ Standpipe Tip

BOREHOLE NO. 7

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 22, 1979

BOREHOLE TYPE BOMBADIER 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE — GEOLOGIST A.B.

ELEVATION 181.1 m — TECHNOLOGIST

DEPTH	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/ 0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.2		TOPSOIL						
		TILL: Medium brown clayey silt till with fractures to 6.4 m, becoming grey brown from 7.6 m hard D.T.P.L.	SS	77	12			
			SS	89	11			
			SS	60	9			
			SS	52	13			
			SS	111	8			
			SS	126	5			
10.7		SHALE: Red with green bands and green mottling, cryptocrystalline, thin to medium bedded shale weathered and odd mud seams to 12.2 m	NX			100		
			NX			100		
15.2		Borehole terminated at 15.2 m in shale						

Piezometer Tip ▲ Standpipe Tip

Gartner Lee Associates Limited

BOREHOLE NO. 8

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 24, 1979

BOREHOLE TYPE BOMBADIER, 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE — GEOLOGIST A.B.

ELEVATION 152.8 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.0		GARBAGE: Alternate layers of garbage and earth fill, moist						
12.5		SHALE: Red, with green beds and green mottling, cryptocrystalline, medium bedded shale, soft, gypsum filled nodules throughout weathered to 13.7 m						
			NX			100		
			NX			100		
			NX			100		
18.3		Borehole terminated at 18.3 m in shale						

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BOREHOLE NO. 9

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92

CLIENT M.M. DILLON LIMITED — DATE JANUARY 25, 1979

BOREHOLE TYPE BOMBADIER 0.1 m I.D. HOLLOW STEM AUGERS — GEOLOGIST A.B.

ELEVATION 141.9 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE				GROUND WATER	REMARKS
			TYPE	BLOW/ 0.3 m	M/C	% RECOVERY		
0.0		WEATHERED SHALE: Red brown weathered shale D.T.P.L.						
1.5		SHALE: Red and green crypto-crystalline shale green bands are hard						
10.7		Borehole terminated at 10.7 m in shale						

● Piezometer Tip ▲ Standpipe Tip

Gartner Lee Associates Limited

BOREHOLE NO. 10

PROJECT NAME BURLINGTON LANDFILL SITE | PROJECT NO. 78-92
CLIENT M.M. DILLON LIMITED | DATE JANUARY 30, 1979
BOREHOLE TYPE BOMBADIER, 0.1 m I.D. HOLLOW STEM AUGERS | GEOLOGIST A.B.
ELEVATION 134.5 m | TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE: TYPE	SAMPLE: BLOW/0.3 m	SAMPLE: M/C	SAMPLE: % RECOVERY	GROUND WATER	REMARKS
0.0								
1.0		FILL: Red brown silty clay fill, D.T.P.L.						
2.4		WEATHERED SHALE						
12.2		SHALE: Red with green bands, cryptocrystalline shale, green bands are hard						
		Borehole terminated at 12.2 m in shale						

● Piezometer Tip ▲ Standpipe Tip

Gartner Lee Associates Limited

BOREHOLE NO. 11

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92
CLIENT M.M. DILLON LIMITED — DATE JANUARY 24, 1979
BOREHOLE TYPE BOMBADIER 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE — GEOLOGIST A.B.
ELEVATION 134.4 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	BLOW/ 0.3 m	M/C	% RECOVERY	GROUND WATER	REMARKS
0.0		FILL: Red brown clayey silt fill, wet						
3.1		GARBAGE: Garbage to 7.6 m saturated					▲	
7.6		SHALE: Red and green banded, cryptocrystalline, thin to thick bedded shale vugs and gypsum nodules throughout.	NX			100		
			NX			100		
			NX			100		
			NX			100	●	
13.7		Borehole terminated at 13.7 m in shale						

● Piezometer Tip ▲ Standpipe Tip

Gartner Lee Associates Limited

BOREHOLE NO. 12

PROJECT NAME BURLINGTON LANDFILL SITE — PROJECT NO. 78-92
CLIENT M.M. DILLON LIMITED — DATE JANUARY 29, 1979
BOREHOLE TYPE BOMBADIER, 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE — GEOLOGIST A.B.
ELEVATION 127.4 m — TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	BLOW/0.3 m	M/C	% RECOVERY	GROUND WATER	REMARKS
0.1		TOPSOIL						
		WEATHERED SHALE: Red brown weathered shale D.T.P.L.						
			SS	32	11		▲	
3.4		hard						
		SHALE: Red and green bands, cryptocrystalline, thick to massive bedded shale vugs and gypsum nodules throughout						
			NX			100		
			NX			100	●	
			NX			100		
			NX			100		
12.2							●	
		Borehole terminated at 12.2 m						

● Piezometer Tip ▲ Standpipe Tip

Gartner Lee Associates Limited

BOREHOLE NO. 13

PROJECT NAME BURLINGTON LANDFILL SITE
PROJECT NO. 78-92
CLIENT M.M. DILLON LIMITED
DATE JANUARY 29, 1979
BOREHOLE TYPE BOMBADIER, 0.1 m I.D. HOLLOW STEM AUGERS NX ROCK CORE
GEOLOGIST A.B.
ELEVATION 122.0
TECHNOLOGIST

DEPTH (m)	STRATIGRAPHY	DESCRIPTION	SAMPLE TYPE	SAMPLE BLOW/ 0.3 m	SAMPLE M/C	SAMPLE % RECOVERY	GROUND WATER	REMARKS
0.1		TOPSOIL						
		WEATHERED SHALE: Red brown weathered shale D.T.P.L. saturated from 1.8 m.						
2.4		SHALE: Red, with green bands and green mottling, crypto-crystalline, massive bedded shale						
							▲	
			NX			100		
			NX			100		
							●	
9.1		Borehole terminated at 9.1 m in shale						

● Piezometer Tip ▲ Standpipe Tip

Test Pit Logs

TEST PIT NO. 1

0-1$\pm$ m

WEATHERED CLAYEY SILT TILL

Brown, moist (at plastic limit) compact, slightly sandy clayey silt till.

SAMPLE #1

Friable, breaking into subangular blocky chunks approximately 10-15$^{\pm}$ mm in size. Roots and Rootlets extend throughout. There are some small fractures and channels along root canals.

1-5.5$^{\pm}$ m

CLAYEY SILT TILL

SAMPLE #2

Brown, very dense, clayey silt till. Occasional pebble of red and blue shale. Soft red and blue-grey nodules of weathered shale throughout. The till is well fractured. Fractures are tight (< .08 mm). Fractures are irregularily spaced apart and trend in all directions. They are seldom con-

SAMPLE #3

tinuous for more than 20$^{\pm}$ cm in the same direction. There are occasional larger fractures up to 1 mm in size. Small solution channels and vugs are present on the fracture faces. From 1-3$^{\pm}$ m the fracture faces are mainly covered with a black staining. From 3-5$\pm$ m the fracture faces are predominantly blue-grey with thin, reddish brown lines of crystallization forming a dendritic pattern on the fracture face. This crystallization appears to be surrounding small rootlet channels penetrating the till to this depth. Throughout the till an occasional fracture face is completely coated with a reddish brown staining. There is one 15 cm wide grey-black, saturated fracture zone extending in a zig-zag pattern vertically downward from 3-5.5$^{\pm}$ m. There is no water seepage from this zone.

The main bulk of the till appears moist. However free water is present in all fractures. There was no water seepage into the pit.

Till breaks up readily into subangular blocky chunks varying in size from very small pieces (2$^{\pm}$ cm) to large blocks (30-60$^{\pm}$ cm). The main bulk of the till is extremely firm, however the material breaks up easily along the fracture planes.

Hole terminated in till at 5.5$^{\pm}$ m.

TEST PIT NO. 2

0-.3$^{\pm}$ m	TOPSOIL Dark brown, moist, crumbly, clayey silt topsoil.
.3-1$^{\pm}$ m SAMPLE #1	WEATHERED CLAYEY SILT TILL Red brown, wetter than plastic limit, compact clayey silt till. Friable, breaking into subangular blocky chunks approximately 10-15$^{\pm}$ mm in size. Roots and rootlets extend throughout. There are some small channels along root canals.
1-5.5$^{\pm}$ m	CLAYEY SILT TILL Till description is similar to test pit #1. Test pit was dry when dug. However water seepage at bottom of hole resulted in 15$^{\pm}$ cm of water ponded in bottom after 1 hour. Hole terminated in till at 5.5$^{\pm}$ m.

TEST PIT NO. 3

0-.3± m	TOPSOIL: Dark brown, moist, crumbly, clayey silt topsoil Dessication cracks are evident on the ground surface nearby.
.3-.6± m SAMPLE #1	WEATHERED CLAYEY SILT TILL: Red brown, wetter than plastic limit, compact, clayey silt till. Friable. Roots and rootlets extend throughout. There are some small fractures and channels along root canals.
.6-1.7± SAMPLE #2	CLAYEY SILT TILL: Till description is similar to test pit #1. However there are very few blue-grey fractures with the reddish-brown crystallization. The till is softer and appears quite a bit wetter at the till-weathered shale contact.
1.7-3.5± m SAMPLE #3	WEATHERED SHALE: Red weathered shale. Completely broken up into small subangular blocky chunks (5-75± mm). The shale is fairly soft. No major fractures evident due to the irregularily broken condition of the shale. Two fractures seen running 124° and 214°. There are grey, horizontal shale bands (10-15± cm thick) spaced .3 to .6± m apart running through this material.
3.5-4± SAMPLE #4	SHALE: Red, shale. Harder than weathered shale. Fractured in mainly two directions, similar to the fractures noted in the weathered shale. Fractures appear very tight (<.08 mm). Bedding planes are horizontal and appear slightly more open than the fractures. The grey, slightly harder, horizontal shale bands extend into this shale at .3 to .6± m spacings. Shale comes out of pit as angular blocks. There was water seepage coming from the weathered shale - hard shale contact. Water level in pit after 1 hour is 3.8± m. Hole terminated in shale at 4± m.

Laboratory

and

Field Test Results

Gartner Lee Associates Limited

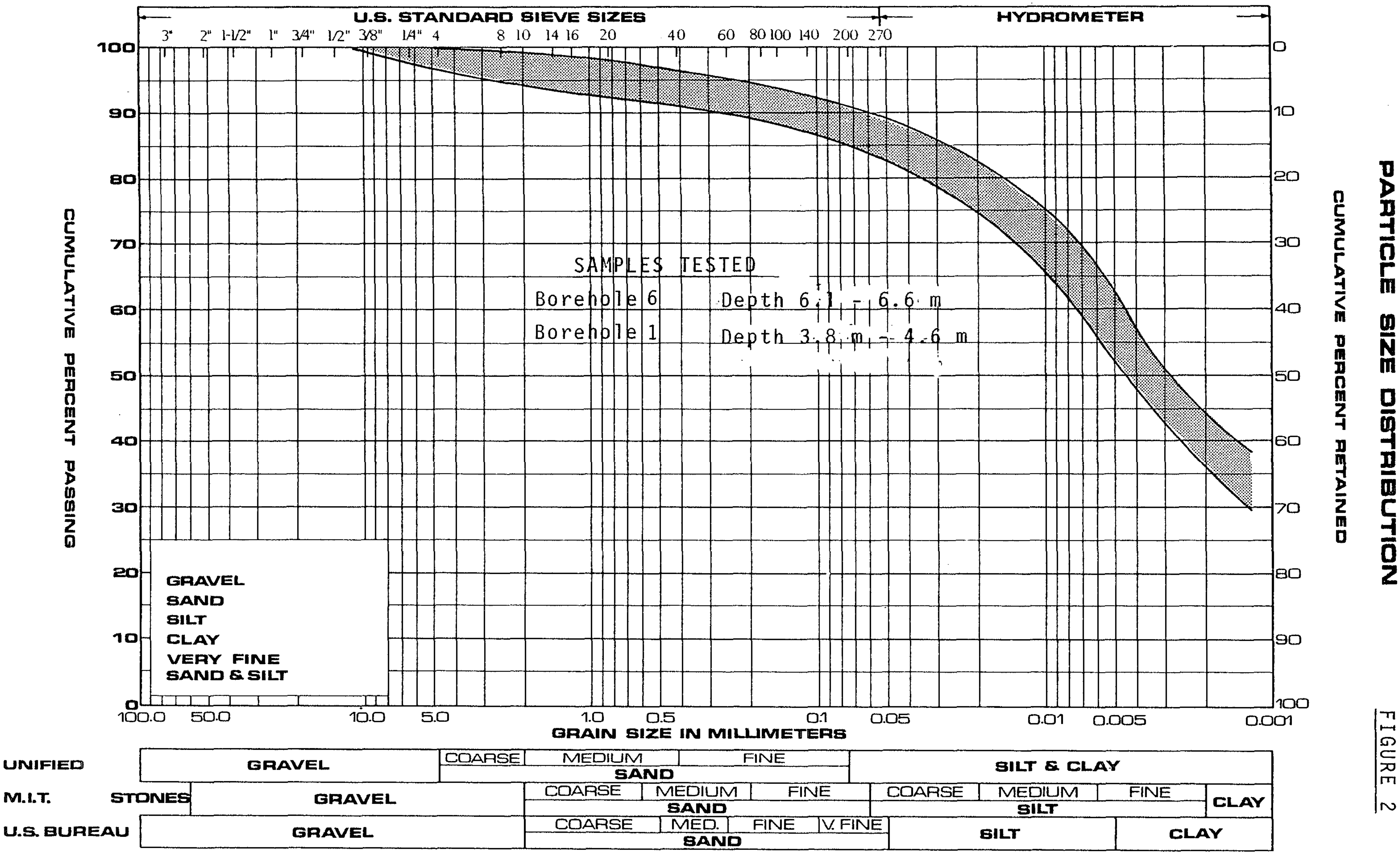


FIGURE 2

JOB NAME BURLINGTON LANDFILL JOB NO. 78-92 HOLE NO. ______ SAMPLE NO. ______

DEPTH ______ REMARKS Gradation Envelope - Clayey Silt Till

ATTERBERG LIMIT TEST RESULTS — TABLE 1

BOREHOLE NO.	DEPTH (m)	LIQUID LIMIT (%)	PLASTICITY INDEX	NATURAL MC(%)	REMARKS
1	3.8-4.6	32	14	--	Clayey Silt
4	6.1-6.6	38	18	12	Inorganic clay of medium plasticity DTPL
7	7.6-8.1	27	11	8	Clayey silt, DTPL
12	1.5-2.0	30	12	11	Clayey silt DTPL (weathered shale)

CATION EXCHANGE CAPACITY RESULTS — TABLE 2

BOREHOLE NO.	DEPTH (m)	CATION EXCHANGE CAPACITY (me/100gm)	SOIL TYPE
1	3.8-4.6	10.0	Clayey silt till
7	7.6-8.1	10.9	Clayey silt till
12	1.5-2.0	14.2	Weathered Shale

CONSTANT HEAD PERMEABILITY RESULTS — TABLE 3

BOREHOLE NO.	DEPTH (m)	UNIT WEIGHT g/cm^3	PERMEABILITY cm/sec	DIRECTION	SOIL TYPE
1	3.8-4.6	2.18	1.3×10^{-7}	Vertical	Clayey silt till

FIELD PERMEABILITY TEST RESULTS

BOREHOLE	DEPTH (m)	PERMEABILITY (cm/sec)		
		Pressure Packer	Slug Test	Material
1	12.8-13.4		$1.22x10^{-6}$	Shale
	16.8-18.3	$1.49x10^{-5}$		Shale
	16.8-18.3	$1.60x10^{-5}$		Shale
	17.7-18.3		$2.45x10^{-6}$	Shale
5	6.9-7.5		$9.40x10^{-7}$	Shale
	7.6-9.1	$1.33x10^{-5}$		Shale
	7.6-9.1	$1.46x10^{-5}$		Shale
	10.7-12.2	$8.50x10^{-6}$		Shale
	10.7-12.2	$9.10x10^{-6}$		Shale
	11.3-12.0		$7.24x10^{-7}$	Shale
7	9.6-10.2		$3.47x10^{-7}$	Clayey Silt Till
12	6.1-7.6	$5.2x10^{-6}$		Shale
	6.4-7.0		$1.11x10^{-6}$	Shale
	9.1-10.7	$1.00x10^{-6}$		Shale
	9.1-10-7	$1.10x10^{-6}$		Shale
	10.6-12.2	$1.80x10^{-6}$		Shale
	10.6-12.2	$1.10x10^{-6}$		Shale
	11.6-12.2		$1.05x10^{-6}$	Shale

Geologic – Sections

APPENDIX 'B'

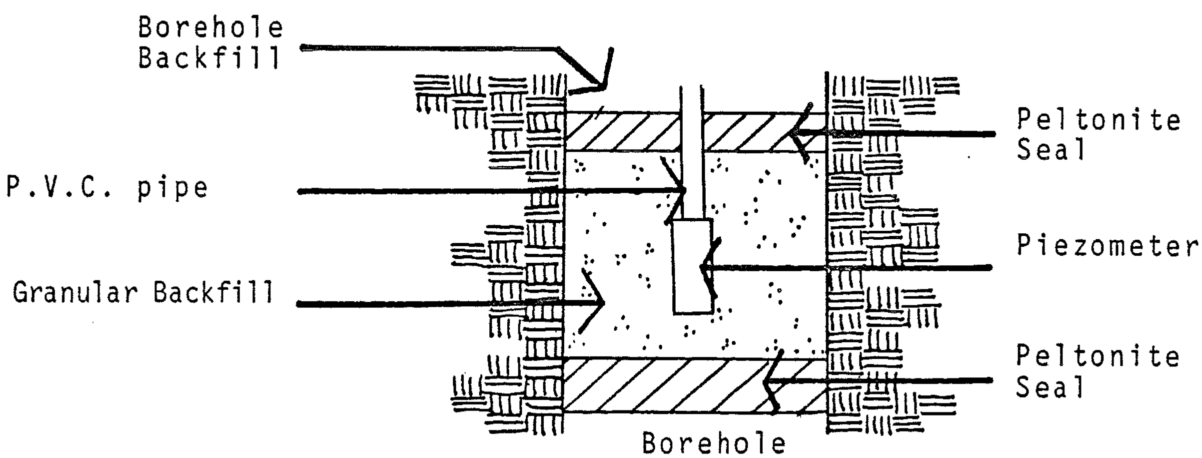
GROUND WATER DETAILS

Ground Water Monitor Details

GROUND WATER MONITOR DETAILS

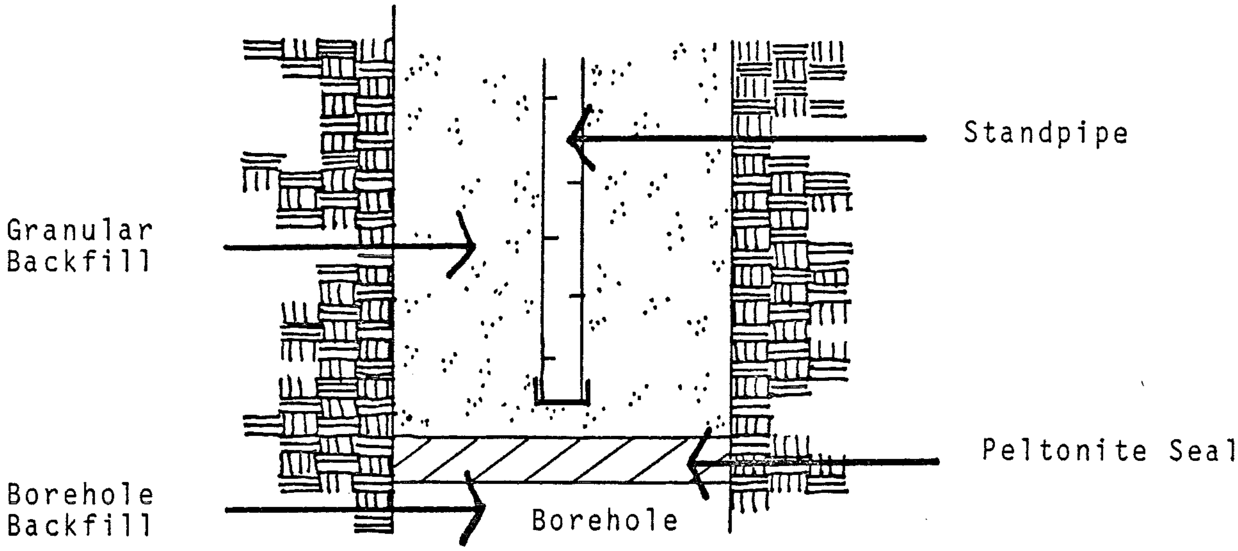
INSTALLATION DETAILS

A. PIEZOMETER: The piezometers consist of PVC pipe slotted and wrapped with fiberglass cloth over .5 m. Piezometers are used to measure the hydrostatic pressure, to obtain ground water samples and to measure in situ permeability.



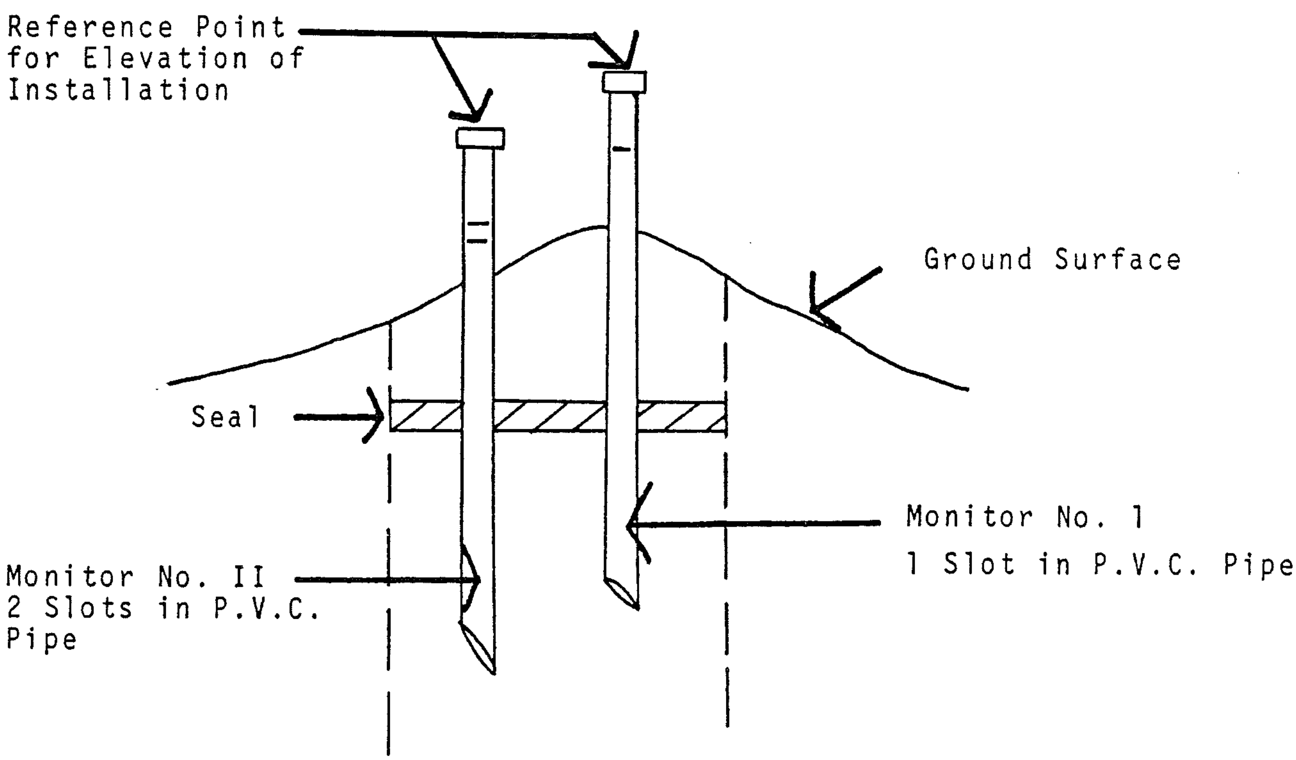
TYPICAL INSTALLATION

B. STANDPIPE: Standpipes consist of P.V.C. pipe with the bottom 2.4 m of each standpipe slotted every .3 m. Standpipes are used to measure the ground water table and to obtain ground water samples. Standpipes in boreholes 8A, 11A, 14, 15, 16 and 17 are slotted from the bottom of the monitor to 0.61 m below the surface.



TYPICAL INSTALLATION

SURFACE DETAILS



PROJECT 78-92 TABLE 5 SHEET 1

GROUND WATER MONITOR DETAILS

EHOLE NO.	*MONITOR				LOCATION OF TIP		LOCATION OF SEAL	
	No.	Diameter mm	Type	Elev.	Depth	Elev.	Depth	Elev.
1	I	32	● trow	183.7	18.6	165.1	18.0	165.7
	II	32	●	184.0	14.0	170.0	14.0, 13.4	170.0, 170.6
	III	19	▲	183.7	6.1	177.6	3.1, 0.9	180.6, 182.8
2	I	19	●	171.7	11.2	160.5	10.6	161.1
	II	19	▲	171.4	7.0	164.4	4.8, 0.9	166.6, 170.5
3	I	19	●	168.2	10.9	157.3	10.3	157.9
	II	19	▲	167.9	6.1	161.8	3.7, 0.9	164.2, 167
4	I	19	●	174.5	14.3	160.2	13.7	160.8
	II	19	▲	174.5	8.5	166.0	5.8, 1.2	168.7, 173.2
5	I	32	● trow	165.3	12.7	152.6	11.9	153.4
	II	32	●	165.1	8.0	158.1	7.4	157.7
	III	19	▲	165.3	5.0	160.3	5.3, 1.2	160.0, 164.1
6	I	19	●	174.2	17.5	156.6	16.8	157.4
	II	19	▲	174.2	11.1	163.1	8.2, 1.1	166.0, 173.1
7	I	32	●	181.5	15.4	166.1	14.8	166.7
	II	32	●	181.8	10.9	170.9	10.8, 10.3	171.0, 171.5
	III	19	▲	181.4	6.1	175.3	6.1, 3.1, 0.9	175.3, 178.3 180.5
8	I	32	●	153.2	18.7	134.5	18.1	135.1
	II	32	▲	153.1	12.5	140.6	12.5, 9.5, 0.9	140.6, 143.6 152.2
9	I	32	●	142.5	11.0	131.5	10.4	132.1
	II	19	●	142.7	8.4	134.3	8.4, 7.8	134.3, 134.9
	III	19	▲	142.9	6.1	136.8	4.0, 1.6	138.9, 141.3
10	I	32	●	134.7	11.9	122.8	11.3	123.4
	II	32	●	134.7	5.8	128.9	5.8, 5.2	128.9, 128.5
	III	19	▲	134.9	3.7	131.2	0.8	134.1
11	I	19	●	135.0	14.3	120.7	13.7	121.3
	II	19	▲	134.9	8.1	126.8	8.1, 5.1, 0.8	126.8, 129.8 134.1
12	I	32	● trow	127.9	12.7	115.2	12.0	115.9
	II	32	●	127.7	7.3	120.4	7.3, 7.0	120.4, 120.7
	III	19	▲	127.9	2.5	125.4	1.1	126.8
13	I	19	●	122.6	9.8	112.8	9.1	113.5
	II	19	▲	122.6	6.1	116.5	3.0, 1.2	119.6, 121.4

* All elevations taken from the top of monitor.

● - Piezometer ▲ - Standpipe

GROUND WATER ELEVATIONS

P. JECT 78-92 TABLE 6 SHEE 1

GROUND WATER ELEVATIONS

BOREHOLE NUMBER	MONITOR No.	MONITOR Type	Feb.26, 1979	Mar.19 1979	Apr.4, 1979	Apr.18, 1979	May 2, 1979	May 16, 1979	June 4, 1979	July 23, 1979			
1	I	⊕	173.4	173.3	173.4	173.1	173.2	173.2	173.3	173.4			
	II	⊕	181.0	181.3	181.5	181.6	181.4	181.4	181.4	181.6			
	III	△	182.8	183.2	183.3	183.2	183.0	183.2	183.0	182.4			
2	I	⊕	168.0	168.3	168.3	168.6	168.4	168.5	168.4	167.5			
	II	△	Frozen	Frozen	171.3	171.1	171.2	171.3	171.3	169.9			
3	I	⊕	163.8	163.0	163.0	163.7	163.5	163.5	163.4	162.4			
	II	△	163.3	163.8	164.8	165.0	164.6	164.6	165.2	162.9			
4	I	⊕	171.2	170.8	170.5	167.9	167.9	166.4	166.6	166.4			
	II	△	170.8	172.3	173.3	173.2	172.8	171.9	172.5	169.5			
5	I	⊕	163.1	163.4	163.2	161.5	155.0	154.0	154.2	154.6			
	II	⊕	Frozen	Frozen	Flowing 165.0	Flowing 165.0	Flowing 165.0	Flowing 165.0	Flowing 164.9	Destroyed			
	III	△	Frozen	Frozen	Flowing 164.7	Flowing 164.7	Flowing 164.7	Flowing 164.7	Flowing 164.7	163.9			
6	I	⊕	160.5	160.2	160.8	160.9	160.9	161.0	161.4	157.8			
	II	△	169.1	169.4	171.5	171.9	170.8	170.9	170.6	168.0			
7	I	⊕	177.8	176.8	176.9	176.8	177.8	177.0	177.4	177.5			
	II	⊕	179.0	179.7	180.0	179.3	180.2	180.3	180.2	178.0			
	III	△	180.8	180.8	180.8	180.7	180.6	180.7	180.5	179.1			
8	I	⊕	136.9	135.5	137.2	136.0	135.3	135.7	135.3	136.5			
	II	△	142.0	141.8	142.2	142.0	141.6	142.0	142.0	148.1			
9	I	⊕	Dry	Dry	Dry	131.8	Dry	Dry	Dry	Dry			
	II	⊕	Dry	Dry	Dry	135.9	135.5	134.8	135.7	Dry			
	III	△	Dry	Dry	Dry	137.1	137.6	Dry	Dry	Dry			
10	I	⊕	128.2	128.5	128.5	129.1	129.0	128.9	129.1	128.2			
	II	⊕	132.7	132.6	132.6	132.9	133.1	132.7	133.0	132.0			
	III	△	132.5	132.4	133.1	133.1	134.2	133.1	133.4	132.8			

PROJECT 78-92 TABLE 6 SHEE 2

GROUND WATER ELEVATIONS

BOREHOLE NUMBER	MONITOR No.	MONITOR Type	Feb.26, 1979	Mar.19, 1979	Apr.4, 1979	Apr.18, 1979	May 2, 1979	May 16, 1979	June 4, 1979	July 23, 1979			
11	I	⊕	128.5	128.6	128.9	127.2	127.3	125.9	126.3	129.6			
	II	▲	130.9	130.7	130.3	130.3	129.6	129.6	129.7	131.5			
12	I	⊕	121.4	121.5	122.1	122.3	122.2	122.1	122.0	121.2			
	II	⊕	122.3	124.9	125.8	124.6	125.2	125.3	125.2	124.3			
	III	▲	126.4	126.9	127.1	127.1	127.2	127.1	126.9	125.8			
13	I	⊕	119.5	120.0	120.6	120.5	120.0	120.0	119.9	119.2			
	II	▲	120.4	121.1	121.7	121.5	121.1	121.2	120.9	120.0			

Ground Water Sections

Background Chemistry

PROJECT 78-92

TABLE 7 SHEET 1

GROUND WATER CONDUCTIVITIES

BOREHOLE NUMBER	MONITOR No.	MONITOR Type	Apr.4, 1979	May 2, 1979	June 4, 1979	July 23 1979							
1	I	●	850	3,050	2,500	3,600							
	II	●	1,200	1,880	1,700	3,400							
	III	▲	550	1,200	1,200	2,600							
2	I	●	920	1,200	1,500	1,200							
	II	▲	920	1,400	1,200	1,900							
3	I	●	420	550	500	750							
	II	▲	620	850	1,000	1,200							
4	I	●	1,150	1,050	1,100	N/A							
	II	▲	890	800	825	1,050							
5	I	●	425	1,175	1,200	1,325							
	II	●	750	550	600	Destroyed							
	III	▲	900	925	980	1,250							
6	I	●	N/A	N/A	N/A	N/A							
	II	▲	690	875	900	1,100							
7	I	●	1,800	1,300	1,500	1,590							
	II	●	500	1,400	1,100	1,200							
	III	▲	550	800	900	1,000							
8	I	●	9,000		>10,000	>10,000							
	II	▲	>10,000	10,000	>10,000	>10,000							
9	I	●	Dry	Dry	Dry	Dry							
	II	●	--	4,000	5,000	Dry							
	III	▲	Dry	Dry	Dry	Dry							
10	I	●	3,000	3,500	3,400	3,600							
	II	●	2,500	2,500	2,600	3,000							
	III	▲	2,100	4,000	4,500	4,700							

● – Piezometer ▲ – Standpipe

Gartner Lee Associates Limited

PROJECT 78-92

TABLE 7 SHEET 2

GROUND WATER CONDUCTIVITIES

BOREHOLE NUMBER	MONITOR No.	MONITOR Type	Apr. 4, 1979	May 2, 1979	June 4, 1979	July 23, 1979
11	I	●	950	1,390	1,350	3,000
	II	▲	>10,000	>10,000	>10,000	>10,000
12	I	●	700	6,000	5,000	6,000
	II	●	2,900	3,400	3,300	3,500
	III	▲	1,900	300	460	6,000
13	I	●	890	4,800	4,500	5,000
	II	▲	1,190	1,700	1,750	1,900
STATION 1			300	500	540	Dry
STATION 2			450	570	550	Dry
STATION 3				1,250	1,300	Dry
STATION 4				1,950	Dry	Dry

● – Piezometer ▲ – Standpipe

Gartner Lee Associates Limited

PROJECT 78-92 | TABLE 8 SHEET 1

WATER ANALYSIS RESULTS

LOCATION BOREHOLE 1, PIEZOMETER 1 | REMARKS

PROPERTY		April 4, 1979	May 2, 1979	June 4, 1979
CONDUCTIVITY µMHOS/CM.		880	3,260	5,400
pH		7.5	7.2	7.5
HARDNESS (Ca CO_3)		238	1,110	1,804
ALKALINITY (Ca CO_3)		204	163	
CHLORIDES (Cl)		47	136	203
SULPHATES (SO_4)		230		2,950
PHOSPHOROUS AS P	Total			
	Soluble			
NITROGEN (N)	Total Kjeldahl	1.6		5.4
	Free Ammonia			
	Nitrite			
	Nitrate			
METALS	Potassium (K)			44
	Magnesium (Mg)			
	Calcium (Ca)			
	Sodium (Na)	105		800
	Iron (Fe)	15	6.0	3.1
PHENOLS (ppb)		<1		
B.O.D.		135		28
C.O.D.				
COLOUR				

PROJECT 78-92 **TABLE** 8 **SHEET** 2

WATER ANALYSIS RESULTS

LOCATION BOREHOLE 8, PIEZOMETER 1 **REMARKS**

DATE / PROPERTY		Apr.4, 1979	June 4, 1979									
CONDUCTIVITY μMHOS/CM.		5,600	20,000									
pH		6.8	7.0									
HARDNESS (Ca CO_3)		1,450	3,866									
ALKALINITY (Ca CO_3)		597										
CHLORIDES (Cl)		2,070	7,160									
SULPHATES (SO_4)		360	420									
PHOSPHOROUS AS P	Total											
	Soluble											
NITROGEN (N)	Total Kjeldahl	10	30									
	Free Ammonia											
	Nitrite											
	Nitrate											
METALS	Potassium (K)		120									
	Magnesium (Mg)											
	Calcium (Ca)											
	Sodium (Na)	740	3,200									
	Iron (Fe)	19										
PHENOLS (ppb)		130										
B.O.D.		560	480									

NOTE: concentrations in p.p.m. unless otherwise noted.

Gartner Lee Associates Limited

PROJECT 78-92 **TABLE** 8 **SHEET** 3

WATER ANALYSIS RESULTS

LOCATION BOREHOLE 8, STANDPIPE 11 **REMARKS**

PROPERTY \ DATE		May 2, 1979	June 4, 1979									
CONDUCTIVITY μMHOS/CM.		13,850	15,600									
pH		5.5	5.7									
HARDNESS ($CaCO_3$)		8,000	10,100									
ALKALINITY ($CaCO_3$)		6,890										
CHLORIDES (Cl)		1,190	13,000									
SULPHATES (SO_4)			750									
PHOSPHOROUS AS P	Total											
	Soluble											
NITROGEN (N)	Total Kjeldahl		720									
	Free Ammonia											
	Nitrite											
	Nitrate											
METALS	Potassium (K)		570									
	Magnesium (Mg)											
	Calcium (Ca)											
	Sodium (Na)		930									
	Iron (Fe)	800	970									
B.O.D.			26,000									

NOTE: concentrations in p.p.m. unless otherwise noted.

Gartner Lee Associates Limited

PROJECT 78-92 **TABLE** 8 **SHEET** 4

WATER ANALYSIS RESULTS

LOCATION BOREHOLE 12, PIEZOMETER 11 **REMARKS**

PROPERTY \ DATE		Apr.4, 1979	May 2, 1979	June 4, 1979								
CONDUCTIVITY μMHOS/CM.		2,970	4,000	3,950								
pH		7.3	7.1	7.6								
HARDNESS ($CaCO_3$)		1,700	1,775	1,744								
ALKALINITY ($CaCO_3$)		228	351									
CHLORIDES (Cl)		118	337	306								
SULPHATES (SO_4)		1,500		1,500								
PHOSPHOROUS AS P	Total											
	Soluble											
NITROGEN (N)	Total Kjeldahl	1.5		1.8								
	Free Ammonia											
	Nitrite											
	Nitrate											
METALS	Potassium (K)			50								
	Magnesium (Mg)											
	Calcium (Ca)											
	Sodium (Na)	210		350								
	Iron (Fe)	4.2	4.1	8.7								
B.O.D.		205		6.0								
PHENOL (ppb)		<1										

NOTE: concentrations in p.p.m. unless otherwise noted.

Gartner Lee Associates Limited

PROJECT 78-92 TABLE 8 SHEET 5

WATER ANALYSIS RESULTS

LOCATION SW STATION 2 REMARKS

PROPERTY \ DATE		Apr.4, 1979	May 2, 1979	June 4, 1979
CONDUCTIVITY μMHOS/CM.		540	630	690
pH		7.9	8.0	8.4
HARDNESS ($CaCO_3$)		254	314	351
ALKALINITY ($CaCO_3$)		185	245	
CHLORIDES (Cl)		35	35	28
SULPHATES (SO_4)		53		61
PHOSPHOROUS AS P	Total			
	Soluble			
NITROGEN (N)	Total Kjeldahl	0.6		0.4
	Free Ammonia			
	Nitrite			
	Nitrate			
METALS	Potassium (K)			3.3
	Magnesium (Mg)			
	Calcium (Ca)			
	Sodium (Na)	18		23
	Iron (Fe)	.95	0.40	0.27
B.O.D.		0.6		1.40
PHENOL (ppb)		<1	1.0	

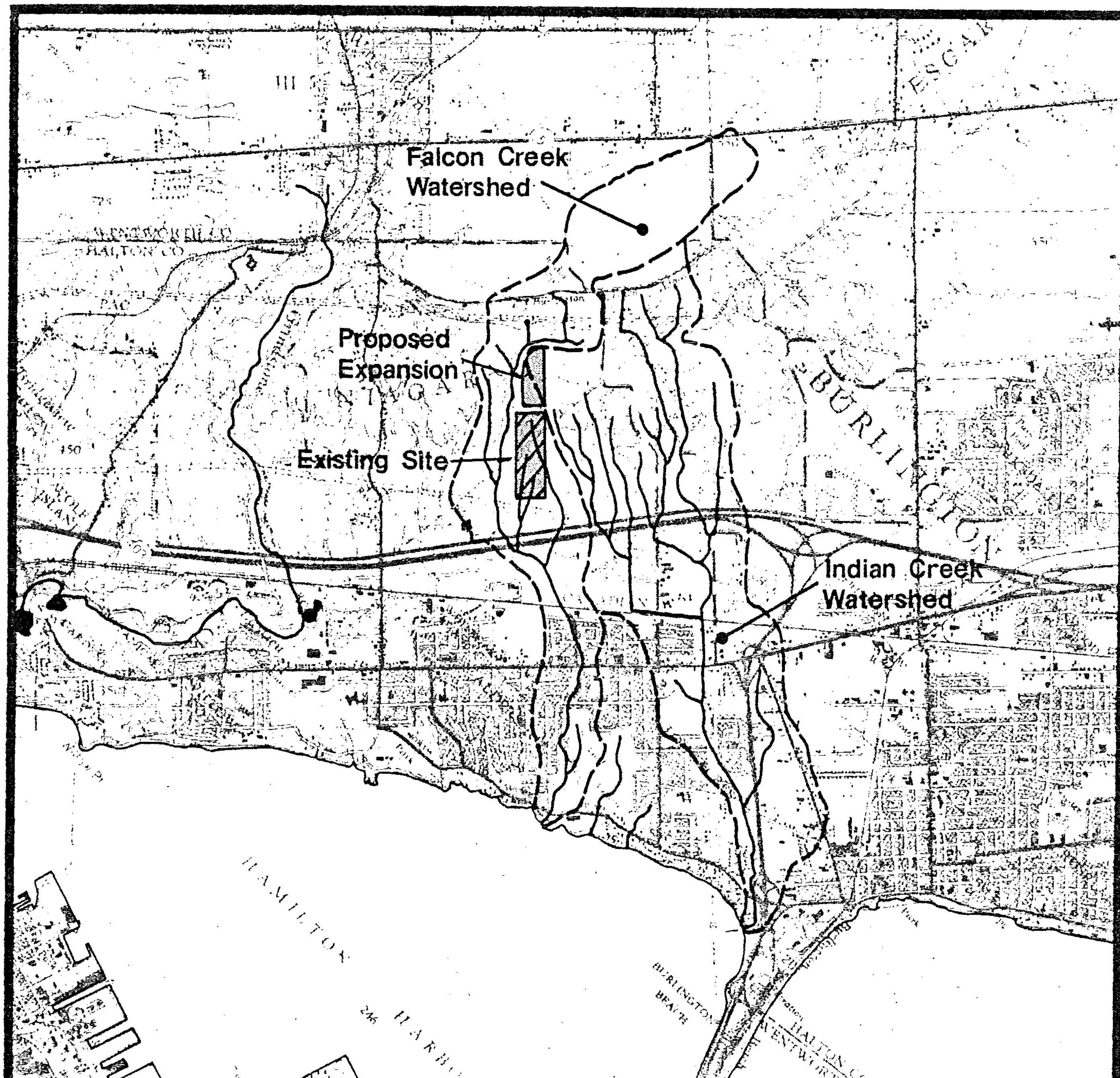
NOTE: concentrations in p.p.m. unless otherwise noted.

Gartner Lee Associates Limited

Ground Water Chemistry
Sections

APPENDIX 'C'

Hydrologic Details



Hydrologic Setting

15

Surface Watershed Divide

Drainage Course

Project 78·92
Scale 1:50,000

FIGURE 3

TEMPERATURE-PRECIPITATION GRAPH

20 YEAR NORMAL

BURLINGTON CLIMATOLOGICAL STATION

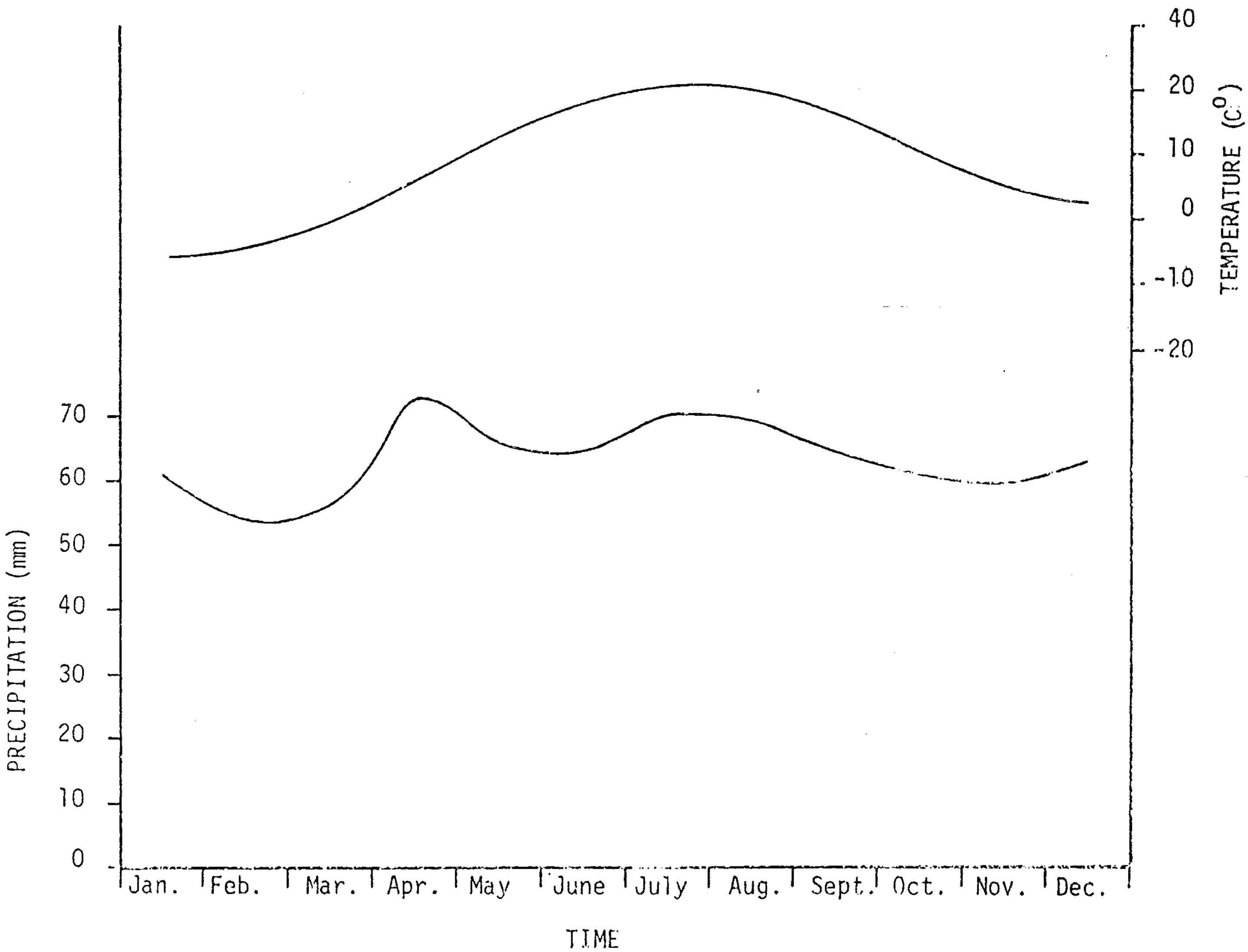


FIGURE 4

POTENTIAL EVAPOTRANSPIRATION

20 YEAR NORMAL

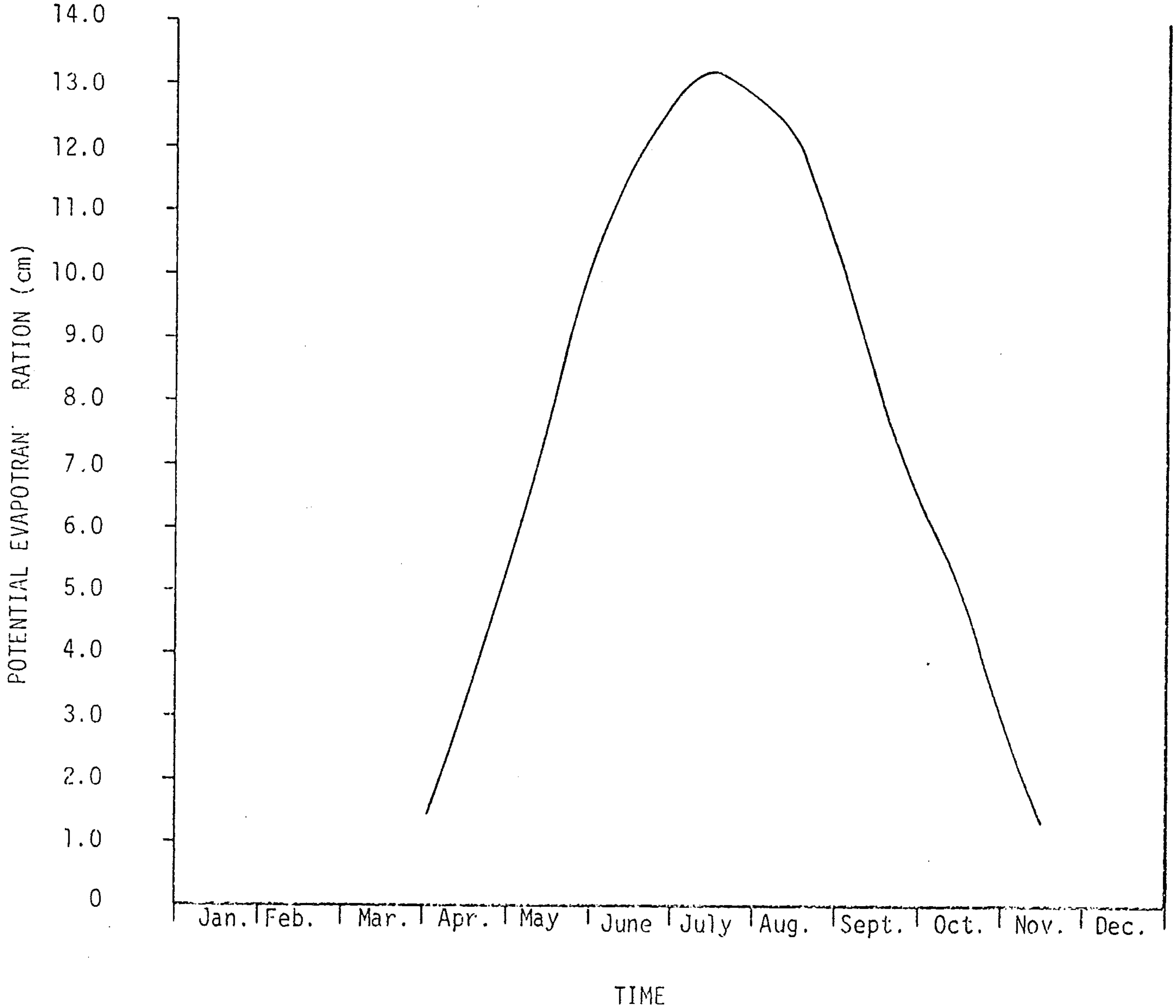
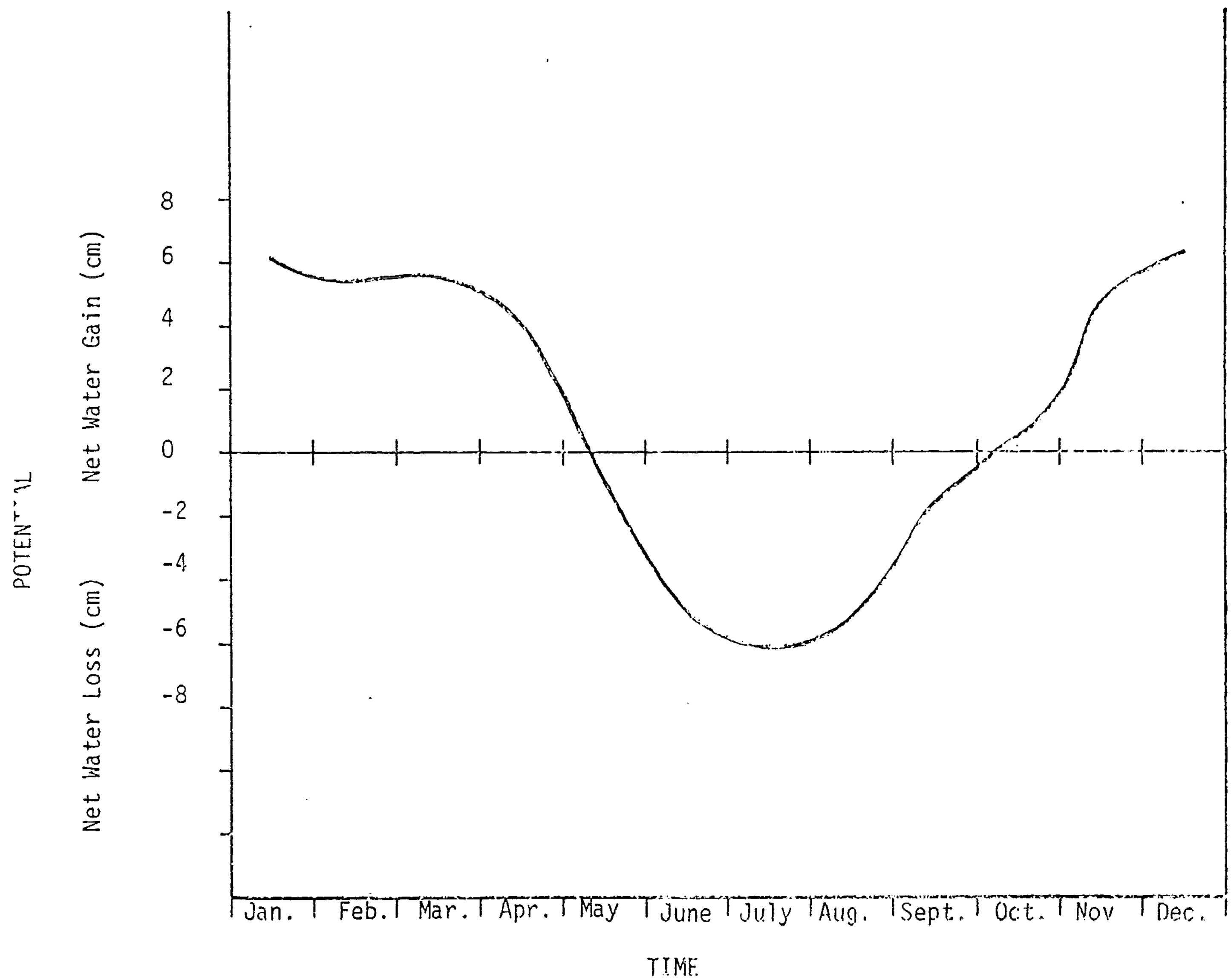


FIGURE 5

WATER BUDGET



PROJECT 78-92

TABLE 9 SHEET 1

SURFACE WATER FLOW

STATION			Apr.4, 1979	Apr.18, 1979	May 2, 1979	May 16 1979	June 4, 1979	July 23, 1979					
1			887	818	887	1,800	682	Dry					
2			887	818	887	1,800	739	Dry					
3					Dry	Dry	Dry	Dry					
4					2.2	59	Dry	Dry					

NOTES:
a) Flow in litres per minute.
b) Water flow is approximate.

● – Piezometer ▲ – Standpipe