



Golder Associates

CONSULTING GEOTECHNICAL AND MINING ENGINEERS

REPORT
TO

THE TOWN OF OAKVILLE

HYDROGEOLOGICAL SUITABILITY OF
CANDIDATE SITES
PROPOSED HALTON REGIONAL
LANDFILL SITE

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EXECUTIVE SUMMARY

Golder Associates was retained by the Town of Oakville to provide an opinion as to the hydrogeological suitability of the Candidate Sites under consideration for selection as the proposed Halton Regional Landfill.

The ultimate measure of suitability for the candidate site selected for development as the Regional Landfill Site should be minimization of any risk associated with the landfill operation, both during its operational life and after final closure.

The risks that are considered to be most important hydrogeologically are risks to public health and safety and the natural environment. These risks include:

- i) Offsite degradation of groundwater resources
- ii) Offsite degradation of surface water resources
- iii) Offsite negative effects on potable water supplies
- iv) Inadequate reaction time to offsite migration provided by the hydrogeological regime
- v) Inability to mitigate uncontrolled releases from a facility

Geological and hydrogeological data concerning the Candidate Sites was reviewed.

Based on Halton Region's proposed landfill design, which constitutes a "minimally engineered" facility, the levels of risk assigned to the six sites are:

	<u>Site</u>
Lowest Risk	D
	E
	F
	A
	B
Highest Risk	C

EXECUTIVE SUMMARY (cont'd)

It is the opinion of Golder Associates that a higher degree of engineered protection is required at any of the Candidate Sites than that proposed to date. Since Candidate Sites B and C were considered those with the highest levels of risk they were excluded from an assessment of risk arising from an "adequately engineered" site.

A description of the level of "adequate engineering" is provided in the report. Based on the effects of these engineered protections, the relative levels of risk associated with landfilling at Sites A, D, E and F are:

	<u>Site</u>
Lowest Risk	<u>D, E, F</u>
Highest Risk	A

When the degree of difficulty of applying "adequate engineering" to each site is considered, the order of preference of the Candidate Sites is considered to be:

	<u>Site</u>
Most Preferred	F
	D
	E
Least Preferred	A

In the report it is demonstrated that Candidate Site A is the least preferred site, whether "minimally engineered" or "adequately engineered" for reasons which include:

1. Geological Variability and Inconsistency of Site
 - i) near surface bedrock
 - ii) surficial and near surface sand and gravel deposits
 - iii) exposure of bedrock and water bearing formations by proposed 4.5 m cut
2. Extremely High Water Table and/or Piezometric Surface
3. Short Calculated Contaminant Breakthrough Times
4. Potential Risk to Groundwater Resources and Potable Water Supplies
5. Potential Risk to Downstream Surface Watercourses

EXECUTIVE SUMMARY (cont'd)

6. High Degree of Engineered Protection Required

- i) sub-liner dewatering system
- ii) imported or synthetic base liner and final cover
- iii) intensive monitoring system

The number and degree of risks and difficulties associated with the development of a secure landfill at Site A justifies its exclusion from further consideration as a Candidate Site for the establishment of the Halton Regional Landfill.

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1. INTRODUCTION

Golder Associates was retained by the Town of Oakville through the legal firm Perry Farley & Onyschuk, on April 16, 1985 to provide an opinion as to the hydrogeological suitability of the six Candidate Sites under consideration for selection as the proposed Halton Regional Landfill.

A preliminary review of the geology and hydrogeology of the six candidate sites for the proposed landfill Site has been completed. The reports and documents reviewed to date are listed below:

- (1) Phase II Hydrogeologic Investigation, National Sewer Pipe Ltd. Landfill Site, Burlington
Morrison Beatty Limited
June 1980
- (2) Hydrological Suitability of the NSPL Landfill Site, Burlington, Ontario
John A. Cherry, Consulting Hydrogeologist
Donald L. Lush, IEC Beak Consultants Ltd.
October 1980
- (3) Phase III Hydrogeologic Investigation, National Sewer Pipe Ltd. Landfill Site, Burlington
Morrison Beatty Limited
November 1981
- (4) National Sewer Pipe Limited Environmental Appraisal
Sanitary Landfill Proposal, Burlington, Ontario
Proctor & Redfern Limited
March 1982
- (5) National Sewer Pipe Limited Design Report, Sanitary Landfill Proposal, Burlington, Ontario
Proctor & Redfern Limited
April 1982
- (6) Evaluation of the National Sewer Pipe Ltd. Burlington Landfill Site
Keros Cartwright, Hydrogeologist
November 15, 1982

- (7) Preliminary Hydrogeological Assessment of Region of Halton Candidate Landfill Site in the Town of Oakville
Terraqua Investigations Ltd.
August 1984
- (8) Draft Summary Report 'S' Phase 2, Stage 2C Selection of Preferred Site
Walker, Wright, Young Associates Limited
January 1985
- (9) Draft Technical Report No. 7 Phase 2, Stage 2C Selection of Preferred Site
Hydrogeologic-Hydrologic Assessment and Conceptual Design
Hydrology Consultants Ltd.
January, 1985
- (10) Draft Technical Report No. 7a Phase 2, Stage 2C Selection of Preferred Site
Hydrogeologic-Hydrologic Assessment and Conceptual Design Appendices
Hydrology Consultants Ltd.
January 1985
- (11) Response to Halton Landfill Environmental Assessment Draft Phase 2, Stage 2C Report
Ecoplans Ltd.
Conestoga-Rovers & Associates Ltd.
March 25, 1985
- (12) Water Well Records for Halton-Peel
Ontario Ministry of the Environment
1978
- (13) Water Well Records for Wentworth County
Ontario Ministry of the Environment
1982

In addition to the above sources, recent field data collected by Terraqua Investigations at the Oakville Site A, and by O.W.M.C. near Milton Site D were examined and where applicable incorporated into the assessment of the six sites contained in this report. The assessment and related comments are based exclusively on an interpretation of the data collected and reported by previous site investigators, whose reports have been reviewed.

Additional data relevant to the six Candidate Sites are contained in reports, which to date have not been reviewed by Golder Associates. These include:

- (1) Regional Landfill Site Hydrogeological Study
Gartner Lee Associates Limited (for M.M. Dillon and
Regional Municipality of Halton)
1978, revised 1980
- (2) Regional Landfill Site Design and Operations Report
M.M. Dillon Ltd.
1978, revised 1980
- (3) Hydrogeological Investigation at the Bayview Park
Landfill
J.A. Cherry, J.P. Hewetson
1983
- (4) Burlington Landfill Site for Continued Use, Volume 2
M.M. Dillon Ltd.
1984

2. OBJECTIVES

The objective in the review of the six candidate sites was to compare the sites under one set of assumed circumstances, on the basis of potential risk.

The principal risk targets being considered in this assessment are public health and safety, and the natural environment, as they may be affected by the hydrogeological/hydrological effects of a sanitary landfill in the vicinity.

All sites were compared on the basis of potential risk under the circumstances of minimally engineered construction and adequately engineered construction, as defined in the text.

3. POTENTIAL RISKS

The ultimate measure of suitability for the candidate site selected for development as the Regional Landfill Site for Halton Region should be the minimization of any risk associated with the landfill operation, both during its operational life and after final closure.

Although none of the six Candidate Sites has been investigated thoroughly enough to definitively identify all of the advantages or shortcomings of the individual sites, enough site specific data is available from each site to allow an assessment of the relative potential degrees of risk at the different site boundaries.

No attempt is made at this stage to identify the levels of various risks which may be acceptable at a given site, only the relative assessment of risk potential as high, medium or low. Golder Associates favours the philosophy that the site(s) with the lowest levels of perceived risk potential are more hydrogeologically suitable for the siting of a sanitary landfill, than are sites with higher levels of perceived risk potential.

The risks that are considered to be most hydrogeologically and hydrologically important are:

- i) Offsite degradation of groundwater resources
- ii) Offsite degradation of surface water resources
- iii) Offsite negative effects on potable water supplies

- iv) Inadequate reaction time to offsite migration provided by hydrogeological regime
- v) Inability to mitigate uncontrolled releases from facility

The assessment of risk relates to the interpretation of data available for a particular site. In the following sections the hydrogeological and interacting portions of the hydrological regimes at each site are described.

4. HYDROGEOLOGICAL INTERPRETATION

A review of the field data available at the time of writing this report was completed in order to interpret the hydrogeological conditions at the six Candidate Sites.

Based on interpreted geology and hydrogeology, the estimated breakthrough time and local effect of leachate migrating from a minimally engineered site have been provided.

4.1 Site A

Three sources of information concerning Site A were reviewed. These include:

- i) Hydrology Consultants field data from Boreholes A1 to A9 inclusive (1984)
- ii) Terraqua Investigations field data from Boreholes 0-1 to 0-8 inclusive (1985)
- iii) Water well records on file with the Ontario Ministry of the Environment

The candidate site is located within the physiographic region known as the Peel Plain (Chapman and Putnam, 1984). The surficial deposits consist mainly of the clayey silt to sandy silt Halton Till, although stratified ice contact or outwash sand and gravel deposits are present above or interfingering with the Halton Till. These granular deposits are most likely chronologically and genetically related to the deposits of the Trafalgar Moraine which lies immediately to the north of

the site. Chapman and Putnam, 1984, identify the "small isolated sandy tract" lying in Concessions VIII and IX of Trafalgar Township (now part of the Town of Oakville), from which numerous water wells obtain domestic water supplies.

Joshua's Creek, and a tributary of Joshua's Creek traverse the site flowing from northwest to southeast. The flow in the tributary watercourses is reported to be intermittent, and is supported, at least seasonally, by local groundwater flow.

A total of nine instrumented borehole nests were constructed during 1984 by Hydrology Consultants, and a further eight were put down by Terraqua Investigations in 1985. The Hydrology Consultants boreholes were sampled at specified intervals by the split spoon method, while continuous sampling was carried out in the Terraqua boreholes. For this reason, more reliance is placed in the Terraqua borehole logs. It should be noted that limitations on the drilling and sampling techniques employed throughout the Hydrology Consultants field investigations were imposed by the drilling equipment being used.

Grain size distribution analyses were completed by Hydrology Consultants on samples obtained from the borehole samples, and water level data and hydraulic conductivity values for this site have been generated by field tests conducted by Hydrology Consultants and Terraqua Investigations.

Based on these data, the site geology is interpreted to consist of the following:

- i) surficial deposit of clayey silt till to silt till (Halton Till) ranging in thickness from 0 m to 6 m, and generally thicker where the bedrock rises to near surface, and found predominantly in the south and east of the site
- ii) surficial stratified sand, silt and gravel deposits ranging in thickness from 0 m to 13 m, and generally present in the north-central portion of the site
- iii) surficial or near surface sandy silt to silty sand till with frequent sand, silt or gravel lenses ranging in thickness from 1 m to 13 m or more. This till is present to some degree at most borehole locations, although it generally thickens to the east and thins in the northwest
- iv) stratified buried sand, silt and gravel channel deposits, ranging in thickness from 0 m to 4 m. These deposits seem to be related to shallow pre-glacial channels cut in the shale bedrock, and trending roughly northwest to southeast. At least two such channels are interpreted to exist in a sub-parallel orientation, separated by a bedrock ridge in the centre of the proposed landfill site
- v) red shale of the Queenston Formation (Upper Ordovician) underlying the overburden deposits, at depth ranging from 2.7 m to 13.8 m below ground surface. The upper few metres of the shale is highly weathered and fractured and has been referred to by Hydrology Consultants and others as the "shale till complex". The more competent shale underlying the weathered zone is highly fractured and is likely to transmit water readily

The groundwater table appears to lie at or close to the ground surface across most of the site during at least certain periods of the year (spring, fall). The lowland areas near the surface watercourses and interpreted minor buried channels are inundated during the spring indicating water table elevations above ground surface. (Terraqua Investigations Borehole 0-7 exhibited a +1.5 m head.) The vertical hydraulic gradients vary from downwards flow (recharge gradient) near the upland areas, to upwards flow (discharge gradients) near the lowland areas, indicating the presence of a local shallow groundwater flow divide running through the centre of the site.

Based on the borehole information, it is interpreted that a 4.5 m cut below surface would remove most of the clayey silt till and expose shale bedrock over approximately 15 per cent of the identified landfill site (generally through the middle portion) and coarse grained deposits of medium sand and/or gravel over an additional 15 per cent. The remaining thickness of sandy silt till would be reduced to a range of 0.1 m to 5.5 m over the remaining 70 per cent of the identified site. A reasonable range of hydraulic conductivity for the various geological strata is proposed below, based on field work completed at Site A and by others in the vicinity and at similar sites in Halton Till.

<u>Strata</u>	<u>Range of K (cm/sec)</u>
clayey silt till	5×10^{-8} to 5×10^{-7}
sandy silt till	5×10^{-7} to 5×10^{-5}
sand and gravel	1×10^{-4} to 1×10^{-2}
upper 2 m of shale bedrock	1×10^{-5} to 1×10^{-3}

The migration paths of contaminants away from the base of any landfill located at Site A would follow the highest hydraulic gradient away from the base. At the centre of the proposed

landfill, near Terraqua Investigations Borehole 0-2, the flow would be downwards under the recharge gradient of 0.12 and then horizontally downgradient under the local observed gradient of 0.006 in the underlying shale bedrock. The application of conventional seepage velocity equations leads to the conclusion that the highest breakthrough time to the shale bedrock aquifer is in the order of 60 years, and to the site boundary a further 20 years (total 80 years).

There are stratigraphic conditions existing beneath other locations within the proposed site where offsite breakthrough times would be substantially less (20 years near BH 0-6, 8 years near BH 0-8). The wide range of calculated breakthrough times (8 to 80 years) reflects the inconsistency in the site geology.

Based on the number of water well records for wells located near Site A, between 10 and 40 domestic water wells within 1 km of the landfill boundary could eventually be affected by offsite migration of leachate from the site, depending on the changes in direction and magnitude of hydraulic gradients which might occur if leachate mounding within a landfill occurred.

The borehole logs produced by both consultants indicate that two sub-parallel shallow bedrock channels, infilled with stratified silt, sand and/or gravel lie beneath the portion of the site identified for landfilling, and that these channels may be separated by a sub-parallel shale bedrock ridge lying within 4.5 m of ground surface. Within this interpreted geological scenario, the borehole evidence indicates a high degree of variability in grain size distribution and strata type throughout the site.

It is probable that the shallow groundwater flow system which is recharged above the bedrock high may discharge to the bedrock channels and coarse grained deposits infilling them, and subsequently daylight in stream beds further downstream in the vicinity of Candidate Site C. These streams eventually join Joshua's Creek and flow to Lake Ontario through urbanized portions of the Town of Oakville.

4.2 Site B

Two sources of information concerning Site B have been reviewed. These include:

- i) Hydrology Consultants field data from Boreholes B1 to B8 inclusive (1984)
- ii) Water well records on file with the Ontario Ministry of the Environment

The candidate site is located within the physiographic region known as the Peel Plain (Chapman and Putnam, 1984), on the south flank of the Trafalgar Moraine. Candidate Site A lies to the northeast and Candidate Site C lies to the east. The surficial deposits consist of clayey silt Halton Till, overlying sandy silt to silty sand till. Shale bedrock is exposed in the bed of an intermittent stream which traverses the property from northwest to southeast. Occasional coarse grained sand and gravel deposits were found within the sandy silt till unit across the site.

A total of eight instrumented borehole nests were constructed during 1984 by Hydrology Consultants. Samples were obtained at specified intervals in these boreholes by the split spoon

method, and grain size distribution analyses were completed on four samples from the site. One hydraulic conductivity test was completed in one of the B4 nest piezometers.

Based exclusively on these data, the site geology is interpreted to consist of the following:

- i) surficial deposit of clayey silt till (Halton Till) over the extreme northwestern portion of the site, ranging in thickness from 2 m to 6 m. This till interfingers with the sandy silt till.
- ii) surficial deposit of sandy silt till over remaining portion of site, ranging in thickness from 0 m to 2.5 m. This till contains frequent sand and gravel lenses.
- iii) red Ordovician shale of the Queenston Formation underlying the sandy silt till at depths varying from 0 m to 12 m below ground surface. The shale depth below ground surface ranges from 8 m to 12 m throughout the northwestern half of the property but is generally less than 3 m over the southeastern half. The shaly clay deposit overlying competent bedrock in Borehole B1 is interpreted to be the upper weathered shale.

The groundwater table generally occurs within 2 m of ground surface across the site, and may rise to near ground surface during high groundwater conditions during the spring and fall. The water table comes to surface at least intermittently in the bed of the stream which traverses the site.

Due to the topography of the site, which consists of a relatively steep decline in elevation from the northern

boundary to the centre of the property, and then a flattening to the southern boundary at Dundas Street, the horizontal hydraulic gradient is relatively high at from 0.013 to 0.02 in the overburden and from 0.006 to 0.01 in the bedrock. An overall vertical discharge (upwards) gradient of 0.015 was measured by Hydrology Consultants on the downward slope of the site, indicating at least seasonal discharge of groundwater to the stream.

Based on the borehole information, it is interpreted that a 4.5 m cut below ground surface would expose shale bedrock over the entire southern half of the site and reduce the thickness of sandy silt till over the shale in the northern portion of the site to from 2 m to 5 m.

A reasonable range of hydraulic conductivity values for the geological strata is proposed below, based on field values obtained by others during investigations in similar deposits.

<u>Strata</u>	<u>Range of K (cm/sec)</u>
sandy silt till	5×10^{-7} to 5×10^{-5}
upper 2 m of shale bedrock	1×10^{-5} to 1×10^{-3}

The migration paths of contaminants away from the base of any landfill located at Site B are principally horizontally through the shale bedrock under the highest hydraulic gradient. The application of conventional seepage velocity equations leads to the conclusion that the breakthrough time to the shale aquifer offsite by leachate generated at a landfill located at Site B, would be on the order of 12.5 years. This time may be substantially lower if localized hydraulic gradients or hydraulic conductivities are higher than estimated.

Based on the number of water well records for wells located near Site B, between 15 and 35 domestic water wells within 1 km of the landfill boundary could eventually be affected by offsite migration of leachate from the site, depending on the changes in direction and magnitude of hydraulic gradients which might occur if leachate mounding within a landfill occurred.

There is evidence suggesting that the intermittent stream flowing southeasterly across the site receives base flow from the local shallow groundwater flow system, and the potential therefore exists that leachate being generated on site could migrate offsite by means of this drainage course or any diversion constructed in its place.

4.3 Site C

Two sources of information concerning Site C have been reviewed, namely:

- i) Hydrology Consultants field data from Boreholes C1 to C9 inclusive (1984)
- ii) Water well records on file with the Ontario Ministry of the Environment

The candidate site is located within the physiographic region known as the Peel Plain (Chapman and Putnam, 1984) on the south flank of the Trafalgar Moraine. The site geology is similar to that at Sites A to the north and B to the west, as the surficial deposits consist of clayey silt (Halton) till at the southwest of the site, grading to sandy silt till over most of the remainder of the site. Shale bedrock occurs within 0.5 m of ground surface at Borehole C6 at the extreme eastern limit of the site.

A total of nine instrumented borehole nests were constructed during 1984 by Hydrology Consultants. Samples were obtained at specified intervals and grain size distribution analyses were completed on seven of them. One hydraulic conductivity test was completed in one of the C2 piezometers.

Based exclusively on these data the site geology is interpreted to consist of the following:

- i) surficial deposit of clayey silt till (Halton Till) over the extreme northwestern portion of the site, ranging in thickness from 2 m to 5 m. This till interfingers with the sandy silt till.
- ii) surficial deposit of sandy silt till over the remainder of the site ranging in thickness from 0.5 m to 12 m.
- iii) randomly interfingered lenses of coarse grained sand and gravel and clayey silt, up to 2 m thick.
- iv) red Ordovician shale of the Queenston Formation underlying the till, and forming a west to east trending channel beneath the centre of the site below the present location of Joshua's Creek. The depth to bedrock varies from 0.5 m to more than 12 m at the borehole locations. The shaly clay deposit reported to overly the competent shale bedrock is interpreted to be the weathered upper surface of the shale.

The groundwater table generally occurs within 2 m of ground surface, and may rise to near ground surface during high groundwater conditions in the spring and fall. The shallow groundwater flow system intersects the ground surface at least intermittently in the bed of Joshua's Creek.

The surface elevation falls steadily across the site from northwest to southeast, and this is reflected in the overburden horizontal hydraulic gradient which ranges from 0.017 to 0.01, and in the bedrock horizontal hydraulic gradient of from 0.003 to 0.01. A vertical discharge (upwards) gradient of 0.35 is reported for most of the site, although a recharge (downwards) gradient of 0.08 was measured in piezometer nest C8. This is not uncommon on sloping terrains, although more data is required to assess the vertical hydraulic gradient at this site confidently. However, at least seasonal discharge to the surface watercourses is indicated.

Based on the borehole information, it is interpreted that a 4.5 m cut below ground surface would expose bedrock over much of the eastern portion of the site, and in isolated areas of the western portion. Sand and gravel would be exposed beneath the centre of the site near Joshua's Creek. The thickness of sandy silt till which would remain above the bedrock in most other locations across the site would be reduced to between 0.5 m and 6 m.

A reasonable range of hydraulic conductivity values for the identified strata is proposed below, based on field values obtained by others during investigations in similar deposits.

<u>Strata</u>	<u>Range of K (cm/sec)</u>
clayey silt till	5×10^{-8} to 5×10^{-7}
sandy silt till	5×10^{-7} to 5×10^{-5}
sand and gravel	1×10^{-4} to 1×10^{-2}
upper 2 m of shale	1×10^{-5} to 1×10^{-3}

The migration paths of contaminants away from the base of any landfill located at Site C are principally horizontally through shallow bedrock aquifers, or vertically downwards to the bedrock, then horizontally, where the vertical hydraulic gradient allows. The application of conventional seepage velocity equations leads to the conclusion that the breakthrough time to the offsite shale aquifer by leachate generated at a landfill located at Site C would be on the order of 12.5 years. The breakthrough time could be substantially lower, if higher than expected hydraulic conductivities or hydraulic gradients are encountered.

Based on the water well records for wells located near Site C, between 10 and 30 domestic water wells within 1 km of the landfill boundary could eventually be affected by offsite migration of leachate from the site, depending on the changes in direction and magnitude of hydraulic gradients which might develop if leachate mounding occurred.

4.4 Site D

Two sources of information concerning Site D directly have been reviewed. These are:

- i) Hydrology Consultants field data from Boreholes D1 to D8 inclusive (1984)
- ii) Water well records on file with the Ontario Ministry of the Environment

In addition, the borehole records from the Ontario Waste Management Corporation site investigation of OWMC Candidate Sites LF-4N and PI-1N are relevant, as OWMC LF-4N is located

immediately adjacent to Site D to the southwest and OWMC PI-1N is located immediately adjacent to Site D to the southeast.

Candidate Site D is located within the physiographic region known as the Peel Plain (Chapman and Putnam, 1984).

The surficial deposits consist primarily of clayey silt till across the entire site.

A total of eight instrumented borehole piezometer nests were constructed on the site during 1984 by Hydrology Consultants. Samples were obtained by the split spoon method at selected intervals, and a total of eleven samples were submitted for grain size distribution analyses. One hydraulic conductivity test was completed in one of the piezometers in the D7 nest.

Five continuously sampled borings were made by Gartner Lee Associates acting on behalf of OWMC at OWMC Candidate Site LF-4N located to the southwest of Candidate Site D, and five continuously sampled borings were made by Gartner Lee at OWMC Candidate Site PI-1N located to the southeast of Site D.

The Gartner Lee and Hydrology Consultants borehole logs agree well on the stratigraphy near Site D. (The increased clay content of these tills relative to the overburden deposits near Site A would allow generally better soil penetration and sample recovery by the drillrig used by Hydrology Consultants in these deposits than in sandy or gravelly deposits. Gartner Lee used the same drillrig and drilling techniques at OWMC Sites LF-4N and PI-1N that Terraqua Investigations used at Site A.)

Based exclusively on these data the site geology is interpreted to consist of the following:

- i) surficial deposit of clayey silt till (Halton Till) over the entire site, ranging in thickness from approximately 7 m to 15 m (some thin sand and silt layers within till).
- ii) lower till unit consisting of stony to sandy silt till, with frequent coarser facies (sand, silt, gravel lenses), varying in thickness from 6 m to 17 m.
- iii) basal layer of silty sand and gravel overlying shale bedrock, ranging in thickness from 0 m to 5.5 m.
- iv) red Ordovician shale of the Queenston Formation underlying the Quaternary overburden deposits ranging in depth below ground surface from 15 m to 35 m or more. It appears that a bedrock ridge occurs near the northwestern boundary, at a subsurface depth of about 15 m, and the bedrock elevation drops in the southeastern direction.

The groundwater table generally occurs within 2 m of ground surface, and may rise to near ground surface during the spring and fall. The shallow groundwater flow system intersects two surface watercourses intermittently as base flow, and may migrate towards the surface watercourse depressions perennially.

The surface elevation across Site D undulates gently but the surface is relatively flat. The horizontal hydraulic gradient in the overburden is reported by Hydrology

Consultants to range from 0.004 to 0.01 and the horizontal hydraulic gradient in the bedrock ranges from 0.002 to 0.006.

An average vertical recharge (downwards) hydraulic gradient of 0.09 was reported by Hydrology Consultants.

Based on the borehole information, it is interpreted that a 4.5 m cut below ground surface would not completely remove the clayey silt till at any location proposed for landfilling. A residual thickness of between 2.5 m and 10.5 m of the clayey silt till would remain above the sandy silt till.

A reasonable range of hydraulic conductivity values for the strata identified at Site D is proposed below, based on field values obtained by others during field investigations in the vicinity in similar deposits.

<u>Strata</u>	<u>Range of K (cm/sec)</u>
clayey silt till	5×10^{-8} to 5×10^{-7}
sandy silt till	5×10^{-7} to 5×10^{-5}
sand and gravel	1×10^{-4} to 1×10^{-2}
upper 2 m of shale	1×10^{-5} to 1×10^{-3}

The migration paths of contaminants away from the base of any landfill located at Site D would follow the highest hydraulic gradient. Downwards migration would occur to the first permeable zone above or at the bedrock surface, and then horizontally offsite. The application of conventional seepage velocity equations leads to the conclusion that the offsite breakthrough time of leachate originating at a Site D landfill could be on the order of 250 years. The breakthrough time could however, be substantially lower if

continuous, connected sand and gravel lenses exist between the base of the landfill and the bedrock surface. In this event, the breakthrough time to an off-site aquifer could be as low as 60 years.

Based on the water well records for wells located near Site D, between 15 and 40 water wells within 1 km of the landfill boundary could eventually be affected by leachate migrating away from the site, depending on the changes in direction and magnitude of hydraulic gradients which might develop if leachate mounding occurs.

4.5 Site E

Two sources of information concerning Site E directly have been reviewed. These are:

- i) Hydrology Consultants field data from Boreholes E1 to E3 inclusive (1984)
- ii) Water well records on file with the Ontario Ministry of the Environment

Candidate Site E is located within the physiographic region known as the Peel Plain (Chapman and Putnam, 1984).

The surficial deposits consist of clayey silt Halton Till across the entire site.

A total of three instrumented borehole nests were constructed on the site during 1984 by Hydrology Consultants. Samples were obtained by the split spoon method at selected intervals and a total of ten samples were analyzed for grain size distributions. No hydraulic conductivity testing was carried out.

Based on these data, the site geology is interpreted to consist of the following:

- i) surficial deposit of clayey silt (Halton) till over the entire site, ranging in thickness from 5 m to 15 m.
- ii) a coarse grained deposit of sand and gravel mixed with silt and some clay lying under the clayey silt till and over a sandy silt till. This thin deposit ranges from 1 m to 5 m thick at the borehole locations.
- iii) a lower till consisting of sandy silt with frequent coarser sand and gravel lenses. The till ranges in thickness from 10 m to 15 m.
- iv) an alternating sequence of fine grained and coarse grained deposits infilling a bedrock depression (channel?) at the south boundary of the Candidate Site. The channel fill reaches a thickness of more than 25 m at the extreme southern site boundary.
- v) red Ordovician shale of the Queenston Formation ranging from 20 m to 40 m below ground surface underlying the overburden deposits. The shale elevation drops off into a probable pre-glacial channel at the south of the site.

The groundwater table generally occurs within 2 m of ground surface across the site, and may rise to near ground surface during the spring and fall.

A tributary of Sixteen Mile Creek flows from northwest to southeast, immediately northeast of the site. It is probable

that some shallow groundwater flow originating at Site E discharges to the watercourse during periods of the year.

The land surface at Site E is generally flat to gently rolling, and there is a slight topographic gradient to the south. The horizontal hydraulic gradient within the overburden is correspondingly low, ranging from 0.0006 to 0.001. The hydraulic gradient within the bedrock is moderately higher than in the overburden, ranging from 0.002 to 0.006.

A vertical discharge (upwards) gradient was observed by Gartner Lee Associates in 1977, and this gradient varied from 0.004 to 0.02. Part of the site, however, exhibited a recharge gradient of 0.06, and it is likely that the majority of the site is a recharge area during the spring.

Based on the borehole information, it is interpreted that a 4.5 m cut below ground surface would not completely remove the clayey silt till at any location proposed for landfilling at Site E. A residual thickness of between 0.5 m and 10.5 m of the clayey silt till would remain above the sand and gravel till and underlying sandy silt till across the site.

A reasonable range of hydraulic conductivity values for strata encountered at Site E is proposed below, based on field values obtained by Gartner Lee during 1977, and others during field investigations in the vicinity and in similar deposits.

<u>Strata</u>	<u>Range of K (cm/sec)</u>
clayey silt till	5×10^{-8} to 5×10^{-7}
sandy silt till	5×10^{-7} to 5×10^{-5}
sand and gravel	1×10^{-4} to 1×10^{-2}
upper 2 m of shale	1×10^{-5} to 1×10^{-3}

The migration paths of contaminants away from the base of any landfill located at Site E would follow the highest hydraulic gradient. Downwards migration would occur to the sandy silt till or to a sand and gravel stratum which was laterally extensive, and from there migration would proceed horizontally offsite. The application of conventional seepage velocity equations leads to the conclusion that the offsite breakthrough time of leachate originating at a Site E landfill could be on the order of 300 years, although breakthrough times as low as 100 years are possible if continuous sand and gravel strata connected to off-site aquifers are encountered.

The water well records for wells located near Site E indicate that between 15 and 25 water wells located within 1 km of the landfill boundary could eventually be affected by leachate migrating away from the site. The formation of a leachate mound within the landfill at Site E could significantly affect the direction and magnitude of the horizontal and vertical hydraulic gradients, thereby affecting the number and location of wells potentially affected.

4.6 Site F

Five sources of information concerning Site F have been reviewed. These are:

- i) Hydrology Consultants field data from Boreholes F1 and F2 (1984)
- ii) Morrison Beatty field data from investigations at National Sewer Pipe Ltd. site (1980, 1981)
- iii) Keros Cartwright investigation for N.S.P.L. (1982)
- iv) John Cherry and Donald Lush study of hydrogeology at N.S.P.L. site (1980)
- v) Water well records on file with the Ontario Ministry of the Environment

Candidate Site F is located within the South Slope physiographic region (Chapman and Putnam, 1984), on the side of the Niagara Escarpment.

Bedrock is exposed over all but the northernmost portion of the site, where a clayey silt till deposit overlies the shale.

Two sampled borings were put down at the north of Site F by Hydrology Consultants in 1984. No instrumentation was left in the boreholes, and no grain size distribution analyses were reported by Hydrology Consultants.

A series of instrumented boreholes was installed on the National Sewer Pipe Ltd. property (Site F) in 1980 and 1981 by Morrison Beatty Limited. Extensive hydraulic conductivity testing in the shale bedrock was carried out during the 1980/1981 study.

Based on the data collected during these previous investigations the site geology is interpreted to consist of the following:

- i) surficial deposit of clayey silt till ranging in depth from 1 m to 15 m over the northern 20 per cent of the site.
- ii) red Ordovician shale of the Queenston Formation exposed at surface or covered by less than 1 m of organic silt topsoil over the remaining 80 per cent of the site

The bedrock slopes steeply to the south, attaining a surface gradient in excess of 30 per cent, and is cut by ravines containing several intermittent tributaries of Indian Creek. The average surface gradient is reported by Hydrology Consultants to be approximately 4 per cent.

According to Morrison Beatty, the water table in the overburden at the north of the site gives rise to the intermittent watercourses which flow southeasterly across the site.

The potentiometric surface varies with the depth in the shale bedrock, but the water levels found within piezometers installed in 1979 and 1980 generally lie between 2 m and 15 m below ground surface. Cherry and Hewetson identified a systematic variation in vertical hydraulic gradient beneath the site, such that recharge gradients exist in the upper 20 m, lateral gradients exist between 20 and 30 m, and discharge gradients exist below 30 m.

Morrison Beatty has established the horizontal hydraulic gradient within the shallow groundwater flow regime as 0.044,

and the direction of flow is generally southeasterly although localized discharge to the intermittent surface watercourses in gullies modifies the flow pattern somewhat.

Based on the existing borehole information, a 4.5 m cut would expose shale bedrock virtually everywhere at the site. A minor thickness of clayey silt till might remain above the bedrock in the northernmost portion of Site F.

The question of vertical distribution of hydraulic conductivity within the shale has been addressed by Morrison Beatty and Cherry and Hewetson and it is agreed that the value drops from 1×10^{-3} cm/sec in the upper few metres to less than 1×10^{-7} cm/sec below 15 m in the rock. However, after the 4.5 m cut the hydraulic conductivity of the exposed shale bedrock is expected to range from 1×10^{-6} cm/sec to 1×10^{-4} cm/sec according to Morrison Beatty Ltd.

The migration path of contaminants away from Site F is not entirely clear, but it seems probable based on the relatively high gradients and the well established regional and local groundwater flow patterns, that contaminant migration would consist of short flow paths in the shallow groundwater system to discharge in the bedrock gullies which house intermittent streams, and relatively long flow paths down to depths of 20-30 m in the shale then by slow horizontal flow towards Lake Ontario.

Cherry and Hewetson have postulated average lateral groundwater flow velocities in the shale to range from 6 m/yr to 130 m/yr, with the velocity decreasing with depth in the rock.

According to Gartner Lee Associates Limited, the vertical flow velocities may range from 0.004 m/yr to 88 m/yr

depending upon both hydraulic conductivity and hydraulic gradient. The lateral flow velocity is estimated by Gartner Lee Associates to range from 0.0006 m/yr at depth, to 15 m/yr nearer to the bedrock surface.

Breakthrough times calculated using conventional equations indicate that offsite migration in the shallow groundwater flow regime may occur in the period from 1 to 17 years after leachate generation, while breakthrough times to Lake Ontario in the deeper flow system range from about 20 to 500 years.

The water well records for wells drilled in the vicinity of Site F indicate that relatively few water wells exist within 1 km of the proposed site. The horizontal hydraulic gradient at Site F strongly favours southward groundwater flow, even in the presence of a substantial leachate mound. Therefore, downgradient wells are the most likely to be eventually affected by leachate contamination. A probable maximum of five wells within 1 km of the landfill boundary are susceptible to effects from the facility, although based on the commonly used criteria of potability or potential for use, the aquifer in many cases is unusable due either to background quality or previous contamination by existing landfill leachate, or both.

5. RISK ASSESSMENT: MINIMALLY ENGINEERED SITE

This section assesses the hydrogeological risk to human health and safety and to the natural environment arising from the establishment of a sanitary landfill site at each of the six Candidate Sites. The hydrogeology of each site has been interpreted in Section 3. In this section it is assumed that the design of the landfill would incorporate only minimal engineering, as proposed in the Hydrology Consultants report.

5.1 Minimal Engineering Defined

In the context of this report, minimal engineering implies that only the following construction engineering techniques would be employed:

- i) grading of base of landfill to one end to facilitate leachate collection
- ii) installation of drainage tiles on base of fill to collect leachate
- iii) collection and disposal of generated leachate
- iv) efficient operation of landfill cells to include daily cover, and cell completion and final covering as rapidly as possible
- v) installation of final cover using native excavated materials, recompacted, graded and vegetated to maximize runoff and minimize erosion

5.2 Definition of Risks to be Assessed

The six Candidate Sites are assessed comparatively on the basis of five principal risks to human health and safety and to the natural environment. These risks are:

- | | | | | | | |
|------|--|-------------|------|---|---|--------------------|
| i) | offsite degradation of groundwater resources | L-M
p 31 | M | D | F | Adverse
Effects |
| ii) | offsite degradation of surface water resources | M-L
p 33 | M-IT | | | |
| iii) | negative effects on offsite potable water supplies | M | L | | | p 35 |
| iv) | inadequate reaction time to offsite migration of contaminants provided by hydrogeological regime | M | H | | | p 37 |
| v) | inability to mitigate uncontrolled releases from facility | M | M | | | |

The relative risk involved with each of these concerns can be assessed based on the hydrogeological interpretation of the sites, and these are described below.

5.2.1 Offsite Degradation of Groundwater Resources

The factors affecting the risk of degradation of groundwater resources are:

- i) attenuative capability of sub-fill layer
- ii) hydraulic gradient (vertical & horizontal) of sub-fill layers
- iii) hydraulic conductivity of sub-fill layers
- iv) proximity of groundwater resources

- v) thickness of sub-base layers
- vi) migration pathways of contaminants
- vii) presence of aquifers

In general, clays and clay-rich soils have relatively higher attenuative capacities than do quartz-rich sands and gravels. Clays have higher cation exchange capacities, which generally allow metal ions (Na, Ca, Mg, K, Fe, Mn) to selectively replace one another on the clay mineral surfaces. Other processes (such as adsorption) are relatively more important in clay soils than in sandy soils, as well. Dilution and dispersion are important processes, particularly for conservative ion contaminants such as chloride and sulphate which are present in landfill leachates. These processes are more likely to be in effect in highly permeable granular deposits such as clean sand and gravel and in fractured bedrock.

Hydraulic gradients, both horizontal and vertical, control both the direction in which groundwater will flow and the velocity of flow.

Hydraulic conductivity is a primary factor in the velocity of groundwater flow, and it is a highly variable parameter, being altered significantly by seemingly minor changes in the content of fine grained silt or clay particles in a soil mass.

The depth to the water table below the base of the fill is an important factor in the assessment of risk to groundwater resources. The greater the distance that contaminated leachate must travel in unsaturated soil, the more attenuation and biodegradation may occur.

The thickness of the soil affects the length of time required for leachate migration in the groundwater regime, and the amount of attenuation which might occur.

Migration pathways may be short and direct to a groundwater resource, or long and convoluted. The same sort of time and attenuation considerations apply to length of migration pathways as apply to thickness of soil.

Obviously the presence of groundwater resources, or aquifers, affects the risk of their degradation. If no aquifer exists, then no degradation can occur.

Based on the foregoing considerations the six Candidate sites have been assigned risk levels of high, medium or low depending on the hydrogeological character as interpreted in Section 3. A brief summary of the risk level assignments with the pertinent factors appears in Appendix A following the text of this report.

Based primarily on the factors of natural attenuative capacities and groundwater flow velocities, Sites A, B and C are considered to pose a relatively high risk to offsite groundwater degradation, while Site D and E pose a low to medium risk, and Site F poses a medium risk to groundwater offsite.

5.2.2 Offsite Degradation of Surface Water Resources

The factors affecting the risk of degradation of surface water resources by landfill leachate migration are:

- i) groundwater flow patterns

- ii) groundwater contribution to stream flow
- iii) proximity of surface water courses to landfill operation

The flow of groundwater from the vicinity of a landfill to a stream is affected by the hydraulic gradient, hydraulic conductivity and the water level in the vicinity of the stream. Often shallow groundwater which is recharged locally will discharge to a nearby stream, while deeper groundwater flow patterns may cause the discharge of water recharged at a much greater distance.

The percentage contribution of groundwater to the total stream flow will affect the amount of degradation of the resource that can occur. A stream that rises from discharging groundwater exclusively may be relatively sensitive to degradation by contaminated groundwater, while a stream that is supported largely by surface runoff may be relatively insensitive to contaminated base flow.

The closer to the landfill the stream exists, the more likely it is that locally recharged groundwater containing leachate will enter the stream. Proximity to the landfill also increases the risk of runoff of leachate from springs at the toe of the fill directly entering the stream.

The risk level assignments are summarized with the pertinent factors in Appendix A. However, due to the proximity of surface water courses to most of the sites, and the degree of groundwater and surface water interaction, all sites are considered to pose medium or medium to high risks to offsite surface water resources.

5.2.3 Negative Effects On Offsite Potable Water Supplies

The factors affecting the risk of degradation of offsite water supplies include:

- i) number of surface water or groundwater potable water supplies in vicinity
- ii) general groundwater migration and soil attenuation characteristics of vicinity (including direction and velocity of flow)
- iii) potential for development of surface water or groundwater potable water supplies in vicinity

Clearly, the risk to potable water supplies increases directly as the number of supplies increases, and the nature of the hydrogeological connection between the source water bodies or aquifer serving these potable supplies, and the source of contaminants is a prime risk factor. The risk may be relatively higher at a site where the potential for water resource development exists compared to a site where no further development can occur.

The risk level assignments for the various sites are summarized with the pertinent factors in Appendix A. Due to the large number of offsite water wells, and the poor natural attenuation at Sites A, B, and C, these sites are considered to pose a relatively high risk to potable water supplies, while the attenuative and natural containment capabilities of Sites D and E reduce the risk to a medium level, despite the presence of nearby wells. Very few water wells are in use near Site F and it is considered to be a relatively low risk to potable water supplies primarily for that reason.

5.2.4 Inadequate Reaction Time to Offsite Migration

Inadequate reaction time relates to the ability to predict and detect migration of contaminants away from a site. The factors affecting this risk are:

- i) stratigraphic complexity of site
- ii) hydrogeological complexity of site
- iii) external influences

The geological conditions which exist beneath a landfill site may range from homogeneous layered clays to heterogeneous mixtures of clay, silt, sand, gravel and bedrock. The less complex the site geology, the more easily a migration pattern can be defined and appropriate corrective action taken.

Secondly, the type of deposit, even if consistent and predictable at the site, will dictate the amount of time available to react. It is reasonable to expect that migration away from a site will be faster through gravel than through clay, for example. Similarly, the degree of complexity of hydraulic gradient and hydraulic conductivity and the presence of perched water tables, may seriously affect the reaction time available after a contaminant release has been identified.

External influences such as municipal drainage works, buildings, buried services with granular bedding trenches and roadways, all serve to complicate the prediction of, and reaction time available, in the event of contaminant releases.

The risk level assignments for the various sites are summarized with the pertinent factors considered in Appendix

A. Largely due to the potential for rapid offsite migration of contaminated groundwater, Sites A and F have been assigned a relatively high level of risk of inadequate reaction time for a release of a contaminant, while Sites B, C and E have been assigned medium to high risk levels and Site D has been assigned a medium level.

5.2.5 Inability to Mitigate

This risk is related to the risk of inadequate reaction time, as it is affected by complexity of stratigraphy and hydrogeology, but it differs in that it is affected by the physical means available to mitigate a problem. For example, a site may consist of a totally unpredictable heterogeneous mix of sand and clay, and have widely varying hydraulic gradients and hydraulic conductivity, but if all the overburden is underlain by a very tight clay or bedrock layer at a reasonably shallow depth, it might be a simple matter to excavate a cut-off interceptor drain all around the site, to collect the migration wherever it goes. On the other hand, deep, consistent clayey silt deposits may be highly consistent and predictable, but it may be very difficult to recover contaminated groundwater from depth in this material.

The risk level assignments for the various sites are summarized, with the factors considered, in Appendix A following the text of the report. For a variety of site specific reasons identified in the Appendix the relative level of risk assigned to Sites B and C is high, while Sites A, D, E and F would impose a medium level of risk of inability to mitigate a leachate release to the environment.

5.3 Comparative Risk at Six Candidate Sites: Minimally Engineered

Table 1 provides a comparison of the levels of risk interpreted in the development of minimally engineered landfills at the six Candidate Sites under consideration for the proposed Halton Regional Landfill. The risks are assessed as low, medium, or high.

On the basis of this comparative evaluation, it can be seen that no site is ideal, and significant levels of risk are involved in the siting of a landfill at any of the sites. In light of the very high level of risk associated with Sites B and C it is proposed to drop them from further consideration at this point. The establishment of a sanitary landfill, as proposed, at Site A also involves a high level of risk, but it will be considered on a comparative basis with Sites D, E, and F in Section 5 of this report which considers an adequately engineered landfill at each of these sites.

The site with the lowest level of perceived risk based on the foregoing assessment is Site D followed closely by Sites E and F and less closely by Site A.

No attempt is made in this consideration to quantify the levels of risk, because no acceptable risk criterion has been established to be used as a reference point. However, it is the opinion of Golder Associates that the design of the proposed landfill should be modified to include a much higher degree of engineered protection.

COMPARATIVE RISK: MINIMALLY
ENGINEERED SITES

	OFFSITE GROUNDWATER DEGRADATION	OFFSITE SURFACE WATER DEGRADATION	OFFSITE NEGATIVE EFFECTS POTABLE WATER SUPPLY	INADEQUATE REACTION TIME	INABILITY TO MITIGATE
A	H	M-H	H	H	M
B	H	M-H	H	M-H	H
C	H	M	H	M-H	H
D	L-M	M	M	M	M
E	L-M	M	M	M-H	M
F	M	M-H	L	H	M

H - HIGH
M - MEDIUM
L - LOW

6. RISK ASSESSMENT: ADEQUATELY ENGINEERED SITE

In this section the four Candidate Sites A, D, E and F have been re-evaluated in light of the relative risk to human health and the natural environment on the basis of the establishment of a landfill site engineered to the level interpreted to be required to provide a reasonable level of security by 1985 landfill technology standards.

6.1 Adequate Engineering Defined

In accordance with current trends in landfill technology, the following engineering features are considered to be required at the landfill sites, as the basis for comparative risk assessment in this section.

- i) base liner equivalent to 1.2 m of 5×10^{-8} cm/sec material
- ii) base liner preparatory foundation (if liner is a synthetic liner)
- iii) base liner protective layer and/or capillary break (if appropriate)
- iv) above liner leachate collection system
- v) leachate treatment or disposal system
- vi) sub-liner dewatering or drainage system as appropriate
- vii) upstream interception of surface water flow (if required)

- viii) daily cover equivalent to 0.15 m of 1×10^{-5} cm/sec material
- ix) final cover equivalent to 1.2 m of 1×10^{-7} cm/sec material covered by 0.9 m granular drainage layer and 0.3 m topsoil growth media, mulched and seeded.
- x) final cover slope not less than 2° and not more than 6°
- xi) assumed compaction of refuse at time of placement

The engineered facilities are also assumed to include monitoring devices as indicated below.

- i) at least one sub-liner area lysimeter to detect leachate migration through liner
- ii) monitoring wells within and outside the landfill mound adequate to assess the vertical and horizontal migration of leachate and background groundwater conditions, and the build-up of groundwater mounds
- iii) stream monitoring for chemical parameters up stream and downstream of landfill
- iv) ongoing monitoring of leachate volumes and chemical character from leachate collection system(s)
- v) ongoing monitoring of water levels in neighbouring water wells, if sub-liner dewatering or drainage in effect

No preference is stated as to materials used for base liner or final cover systems, although the native material

available on site at the various sites is a consideration in the cost of constructing the liner. No assessment of cost has been attempted, but availability of materials is considered.

6.2 Engineering Interpreted To Be Required At Conditate Sites

In this section, a brief description of the degree of engineered system required at each site is provided. The objectives are similar for each site, in that the engineering criteria set out in Section 5.1 must be met in each case.

6.2.1 Site A

At Site A the surficial materials exposed on site after the removal of a 4.5 m cut will consist of shale, sand and gravel, and/or sandy silt till. These materials clearly do not meet the base liner requirements. A liner constructed of either synthetic membrane placed on a granular base and covered with silty or clayey material, imported natural clay material, or augmented native till may be used.

Due to the very high water table or piezometric surface elevation exhibited in Terraqua Investigations boreholes 0-7 and 0-8 sub-liner dewatering and/or drainage would probably be required. Active pumping may be required to lower the head to a point where the stability of the liner against uplift will be assured.

A leachate collection system consisting of gravel bedded drainage pipes spaced in accordance with the hydraulic design of the system would drain to a series of collection sumps for pumping via approximately 2 to 3 km of new sewer to the Town

of Oakville sewer system in place at Dundas Street and Trafalgar Road. Depending upon the anticipated strength of leachate and the capacity of the Oakville Sewage Treatment Plant, partial on-site treatment of leachate may be required.

It is anticipated that daily cover requirements can be met by carefully selected native excavated materials, but the final cover materials will likely be similar to those used in the base liner.

The regional and local groundwater and surface water flow paths are relatively well defined at Site A, and therefore a moderate number of monitoring wells outside the landfill will be required. At least one monitoring well will be required in each cell of the landfill mound. Due to the shallow overburden and bedrock conditions in the vicinity of Site A, the monitoring wells will be relatively shallow, and the nests would consist typically of two to three piezometers.

Surface water quality monitoring in Joshua's Creek would be required at one upstream and at least three downstream stations. Water level monitoring in selected water wells within 1 km of the landfill boundary should be carried out twice yearly to determine the effects of sub-liner dewatering.

6.2.2 Site D

The exposed materials after a 4.5 m cut at Site D would generally consist of clayey silt till. While the same options exist at this site for base liner construction as exist at Site A, the native soils are likely to be suitable for mixing with soil additives in a batch operation and recompacted in thin lifts to form the liner.

The water table at Site D is likely to be seasonally very high, and therefore sub-liner dewatering and/or drainage may be required, which may demand active pumping during periods of the year and gravity drainage during the rest of the year.

Leachate collection above the liner would be required at Site D, using a similar system to the one discribed for Site A. The length of sewer line required to deliver leachate to the nearest existing municipal sewer line is unknown at this time, but it is likely to be more extensive than the system to be required at Site A. The strength of leachate anticipated and the capacity of the eventual end point sewage treatment plant to accept the leachate loading will determine whether partial on-site leachate treatment will be required.

Daily cover material requirements can most probably be met by native on-site soils, and these same soils may be suitable for use in the final cover design with appropriate treatment and augmentation.

Due to the very low hydraulic gradients present near the site, a low degree of confidence regarding probable ground-water borne leachate migration direction exists. Therefore a relatively large number of monitoring wells would be required outside the fill, and at least one monitoring well per land-fill cell would be required within the mound.

Due to the generally thicker till deposits at Site D, and the presence of granular deposits at greater depths within these tills, the monitoring wells would of necessity be relatively deep, and piezometer nests may typically consist of 3 to 5 piezometers.

Surface water monitoring would be required upstream of the site in the tributary of Sixteen Mile Creek, and at at least three locations downstream, terminating at the confluence with the main channel of the creek.

Water level monitoring in selected wells located within 1 km of the landfill boundary would be required as at Site A to determine the effects of sub-liner dewatering.

6.2.3 Site E

The exposed materials after a 4.5 m cut at Site E would generally consist of clayey silt till, although some areas of sandy till to sandy silt till might be exposed. Like Site D, it is probable that an engineered base liner could be constructed using augmented and reworked native material although any liner system which meets the previously stated criterion would be considered to be acceptable.

The water table condition at Site E is comparable to that at Site D, indicating the probable requirement for sub-liner dewatering and/or drainage, which might require pumping as well as gravity drainage.

Leachate collection will be required above the liner as described in previous sections, and the piping distance for leachate disposal is not known at this time, but may be comparable to Site D and greater than at Site A.

The requirement, if any, for partial on-site leachate treatment will be determined based on the factors previously discussed.

Daily cover material requirements can most probably be met by native on-site soils, and these same soils may be suitable for inclusion in the final cover design with appropriate treatment and augmentation.

The monitoring well system required at Site E will be similar to that required at Site D, although a moderately higher number of wells may be required in the vicinity of the buried channel deposits.

Surface water monitoring at Site E would consist of upstream monitoring of the southeasterly flowing stream, and downstream monitoring at at least three points in that stream and three points in the westerly flowing ditch.

Water level monitoring at selected water wells around the site may be required twice yearly to determine the effects of sub-liner dewatering.

6.2.4 Site F

The material exposed after a 4.5 m cut at Site F would consist of fractured shale of the Queenston Formation.

Gartner Lee Associates describe the consistency of the upper weathered shale which is to be removed at the site as having a "clayey silt" texture. If this is the case over a sufficiently large portion of the site, it is possible that this material could be reworked and augmented if necessary to meet the base liner criteria. Failing this, two other sources of liner material may be available. Firstly, the clayey silt till found at the north of the site may be used as described at Sites D and E, if present in sufficient volume to be used as borrow without creating other hydrologi-

cal or hydrogeological problems arising from its removal. Secondly, a synthetic membrane liner system may be adopted at the site.

The groundwater level conditions at Site F would seem to favour the installation of a base liner without major sub-liner dewatering or drainage. Localized sub-drains might be required during high groundwater conditions, however.

Leachate collection will be required above the liner, as described for Sites A, D and E and connection to the Town of Burlington sewer system can be made without extensive construction of feeder lines. It is doubtful that any on-site leachate treatment would be required based on the assumed capacity of the Burlington Sewage Treatment Plant.

Due to the relatively steep surface gradient at Site F, an upstream surface water interception trench will be required to divert surface runoff around the site.

It is probable that daily cover material requirements can be met by native on-site materials, but the suitability of these materials for use in the final cover design is subject to the same questions raised for its use as sub-liner material. Prior to any eventual decision on sub-liner or final cover designs at any of these sites, extensive on-site soil investigation and laboratory batch testing of design mixtures should be carried out.

The high horizontal hydraulic gradient in place at Site F dictates that southeasterly migration of leachate is the most probable migration path. Therefore relatively fewer monitoring wells may be required upgradient of Site F than at Sites A, D and E. The depth and complexity of the piezometer nests

would be higher than at Site A and equal to Sites D and E, although with the large number of monitoring wells in place at or near Site F, it is probable that some could be saved during construction and incorporated into the monitoring system.

At least one monitoring well per landfill cell should be installed within the mound.

Surface water monitoring upstream of the landfill will be required in all surface water courses which traverse the site, and downstream monitoring should be carried out at at least three locations in each stream when flows allow.

6.3 Comparative Levels of Engineering at Six Candidate Sites

Table 2 summarizes the level of engineering required at each of Candidate Sites A, D, E and F.

6.4 Comparative Risk at Candidate Sites: Adequately Engineered

If it is assumed that any of the Candidate Sites can be adequately engineered to the same degree with the same ease, and the same cost, then the only basis for comparison would be the natural conditions at each site, since these provide the "final line of defence" against a failure of the engineered system.

The only two factors that may change based on the application of engineering design at Sites A, D, E and F, are the off-site effects on groundwater resources, and the off-site negative effects on potable water supplies. This arises due to the

LEVEL OF REQUIRED ENGINEERING
AT CANDIDATE SITES

A	D	E	F	
*	*	*	*	BASE LINER
*	*	*		SUB LINER DEWATERING OR DRAINAGE
*	*	*	*	LEACHATE COLLECTION TREATMENT A/O DISPOSAL
			*	UPSTREAM SURFACE WATER INTERCEPTION
*	*	*	*	ENGINEERED FINAL COVER
*	*	*	*	MONITORING WELLS WITHIN MOUND
*	*	*	*	SHALLOW MONITORING WELLS OUTSIDE MOUND
	*	*	*	DEEP MONITORING WELLS OUTSIDE MOUND
*	*	*		MONITORING OF WATER LEVELS IN AREA WELLS
*	*	*	*	MONITORING OF SURFACE WATER

varying degree of sub-liner dewatering or drainage envisaged at the sites, and the related potential for groundwater level lowering in general, and the lowering of domestic water supply wells in specific.

At Site A, the high water table and proximity of pervious water bearing zones to the surface may dictate that a sub-liner dewatering system employing sumps and pumps be installed. In this event, it is possible that the water level in neighbouring wells could be noticeably lowered after prolonged pumping. The level of risk of groundwater resource degradation and degradation of potable water supplies is already considered to be high, and the potential dewatering problems merely reinforce the high risk.

At Sites D and E the potential need for sub-liner water table lowering arises due to a high water table. The relatively low permeability of the overburden deposits will probably allow gravity drainage rather than active pumping, but some limited regional groundwater lowering could take place. Therefore, the risk levels associated with groundwater degradation and potable water supply degradation are potentially marginally higher.

As no sub-liner drainage is anticipated at Site F, and as there are very few groundwater supply consumers near the site, no change in risk level is considered necessary at that site.

Table 3 reassesses the risks involved with the hydrogeological performance at Sites A,D,E and F.

On the basis of this comparative analysis, it can be seen that Site A becomes even less favourable for the establish-

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TABLE 3

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COMPARATIVE RISK: ADEQUATELY
ENGINEERED SITES

Adequately
Engineered
P

- i) L M M
- ii) M M-H
- iii) M-H L
- iv) M H
- v) M M

H - HIGH
M - MEDIUM
L - LOW

Note only change in
(iii) and

	OFFSITE GROUNDWATER DEGRADATION	OFFSITE SURFACE WATER DEGRADATION	OFFSITE NEGATIVE EFFECTS TO POTABLE WATER SUPPLY	INADEQUATE REACTION + TIME	INABILITY TO MITIGATE	
A	H	M-H	H	H	M	NO CHANGE AS GROUNDWATER AND POTABLE WATER SUPPLY ALREADY HIGHLY AFFECTED
D	M	M	M-H	M	M	POSSIBLE DEWATERING OF LOCAL GROUNDWATER AND LOCAL WELLS
E	M	M	M-H	H	M	POSSIBLE DEWATERING OF LOCAL GROUNDWATER AND LOCAL WELLS
F	M	M-H	L	H	M	NO CHANGE

ment of a landfill site, while the remaining Sites D, E and F are all more favourable than Site A, but then relative order of preference becomes less clear.

6.5 Assessment of Degree of Difficulty of Application of Engineered Design

Due to the fact that different Candidate Sites in fact require different levels of engineering design and construction to bring them to an adequate standard of secure landfill technology in 1985, as described in Section 5.2.1 to 5.2.4. of this report, Table 4 provides a comparison of the degree of difficulty of designing, constructing and maintaining the various engineered components. The level of difficulty considers such factors as availability and suitability of materials for liner and cover, the requirement for pre-construction engineering, such as installation of dewatering systems, the difficulty of collecting and disposing of leachate, the ongoing maintainance requirements and the degree and difficulty of monitoring. Only relative cost considerations are incorporated in this assessment. The degree of difficulty is rated as high, medium, or low.

No attempt has been made to quantify the degree of difficulty involved in this assessment, but based on the comparative evaluation in Table 4, Site F emerges as the preferred site. Sites D and E rank as second and third respectively, and there is only a minor difference in the perceived ranking. These two sites, however, appear to be significantly more difficult to engineer than Site F. Site A ranks as the least desirable site based on degree of difficulty to engineer.

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RELATIVE DEGREE OF DIFFICULTY IN
ENGINEERING SITES

degree of difficulty

	ADEQUATE BASE LINER (1)	PRE-CONSTRUCTION ENGINEERING 2	COLLECTION AND DISPOSAL OF LEACHATE 3	MAINTANANCE RESERVATIONS 4	ONSITE AND OFFSITE MONITORING	FINAL COVER DESIGN
A	H	H	M	M	M-H	H
D	L	H	H	M-H	H	L
E	L-M	H	H	M-H	H	L
F	L-M	M	L	M	M	M-H

degree of difficulty

H - HIGH
M - MEDIUM
L - LOW

Site A is more difficult to engineer because there is not a large deposit of relatively low permeability clayey silt till available from landfill excavation which could be used as a component of base liner or final cover element. The requirement for sub-liner dewatering is most probable at Site A and the degree of monitoring, including both water quality and groundwater levels is anticipated to be moderately high.

At Site D, a relatively low degree of difficulty is anticipated in using on-site clayey silt till as a major component of base liner and final cover designs. However, the high water table will probably require an extensive gravity drainage system, and the disposal of collected groundwater and leachate may require a lengthy sewer line. A relatively extensive network of monitoring wells will also likely be required at Site D.

At Site E, the native, on-site clayey silt till is similar to Site D, although the presence of coarse grained facies could require careful screening of the materials being selected for use. In most other aspects, Site E is similar to Site D.

At Site F, the likelihood of an on-site source of acceptable material instead of a systematic membrane for use in final cover and base liner systems depends on the workability of the shale bedrock. It is probable that an upstream interception trench will be required to divert surface runoff which is likely to move downslope in the spring and during rainfall events. This interception trench would likely require less engineering than a sub-liner drainage system, which is not anticipated to be required due to the relatively low water table or piezometric surface.

The connection of the leachate collection system to the Town of Burlington sewer system is not anticipated to require extensive construction.

Due to the strong hydraulic gradients present near Site F, the monitoring well network can be concentrated in the downgradient direction, and some of the many existing wells may be incorporated into the final system required.

7. OVERALL RANKING OF CANDIDATE SITES

The six Candidate Sites identified for potential development as the proposed Halton Regional Sanitary Landfill have been assessed hydrogeologically on the basis of risk to human health and safety and the natural environment, under the circumstances of "minimally engineered" design and "adequately engineered" design.

As developed in Sections 4 and 5 of this report, the relative rankings of the sites appear below (Sites B and C were dropped from consideration after the initial assessment).

Minimally Engineered

	<u>Site</u>
Lowest Risk	D
	E
	F
Highest Risk	A

Adequately Engineered

	<u>Site</u>
Lowest Risk	D, E, F
Highest Risk	A

A further assessment of the degree of difficulty of designing, constructing, and maintaining an adequate level of secure engineered landfill, based on a 1985 level of technology was completed in Section 5.5.

The relative rankings arising from this assessment are:

	<u>Site</u>
Lowest Degree of Difficulty	F
	D
	E
Highest Degree of Difficulty	A

The resultant ranking of sites as most desirable to least desirable based on hydrogeological risk to human health and safety and to the natural environment appears below.

Rankings are provided for both the "minimally engineered" case and the "adequately engineered" case, although it is the opinion of Golder Associates that the level of hydrogeological risk may be too high at all of the sites if only "minimally engineered" landfill designs are selected.

Minimally Engineered

Adequately Engineered

Most Preferred D
 E
 F

Least Preferred A

Most Preferred F
 D
 E

Least Preferred A

It has been demonstrated by the foregoing analyses that Candidate Site A is the least preferred of Sites A, D, E and F for reasons discussed in detail in Sections 5 and 6 of this report. These reasons may be summarized as follows:

A Geological Variability and Inconsistency of Site

- i) near surface bedrock
- ii) surficial and near surface sand and gravel deposits
- iii) exposure of bedrock and water bearing formations
 by 4.5 m cut below surface

B Extremely High Water Table and/Or Piezometric Surface

C Short Calculated Contaminant Breakthrough Times

D Potential Risk to Groundwater Resources and Potable
 Water Supplies

E Potential Risk to Downgradient Surface Watercourses

F High Level of Engineering Required

- i) sub-liner dewatering
- ii) imported and for synthetic base liner and final cover
- iii) intensive monitoring system

The number and degree of risks and difficulties associated with the development of a landfill at Site A justifies, in the opinion of Golder Associates, its removal from further consideration as a Candidate Site for the establishment of the Halton Regional Landfill.

GOLDER ASSOCIATES


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Denys W. Reades, P. Eng.

REFERENCES

1. Chapman, L.J. and D.F. Putnam, The Physiography of Southern Ontario 3rd Edition. Ontario Geological Survey Special Volume 2 1984.

APPENDIX A

SITE BY SITE COMPARISON OF
RISK LEVELS AND RISK FACTORS

APPENDIX ASITE BY SITE COMPARISON OF
RISK LEVELS AND RISK FACTORS

Factors For Minimally Engineered Site:

NOTE: (+) indicates relatively favourable factor
(±) indicates relatively neutral factor
(-) indicates relatively unfavourable factor

A.1 Risk of Offsite Degradation of Groundwater Resources

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
A	High	(-) poor attenuative capacity where bedrock and sand and gravel exposed (±) moderate hydraulic gradient (-) unpredictable hydraulic conductivity, with probable areas of high hydraulic conductivity (-) very high water table and proximity to surface of water bearing zones (-) minimal thickness contain- ing materials beneath fill (-) rapid and accessible migration pathways

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
C	High	(-) high water table (-) little or no overburden below fill (-) rapid and accessible migration pathways (-) base of fill in contact with shale aquifer
D	Low to Medium	(+) relatively good attenuative capacity in clayey silt till and silt till (+) low hydraulic gradient (+) relatively low hydraulic conductivity in clayey silt till (-) moderately high water table (+) up to 25 m of silty overburden between fill and bedrock (+) migration pathways limited and buried by significant confining layers

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
A	High	(-) proximity of aquifer in contact with fill
B	High	(-) little or no attenuative capacity (-) relatively high hydraulic gradient (-) relatively high and unpredictable hydraulic conductivity (-) high water table (-) little to no overburden below fill (-) rapid and accessible migration pathways (-) base of fill in contact with shale aquifer
C	High	(-) little or no attenuative capacity (-) relatively high hydraulic gradient (-) relatively high and unpredictable hydraulic conductivity

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
D	Low to Medium	(±) base of fill not likely in contact with aquifers, although contact with granular materials possible
E	Low to Medium	(+) relatively good attenuative capacity in clayey silt till and silt till deposits (+) very low hydraulic gradient (+) relatively low hydraulic conductivity in clayey silt till (-) moderately high water table (+) up to 20 m of silty over- burden under most of fill area between fill and bed- rock (±) migration pathways generally limited and buried beneath clayey silt till but presence of buried channel is a neg- ative aspect to be considered (±) base of fill not likely in contact with aquifers al- though contact with granular materials possible

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
F	Medium	(+) moderately good attenuative capacity in shale bedrock, although flow velocity may not allow sufficient contact time → (-) very high hydraulic gradient (+) variable and unpredictable hydraulic conductivity which however, generally decreases with depth (+) water table generally below 4.5m below ground surface → (-) essentially no overburden between base of fill and bedrock → (+) migration pathways very accessible but regionally predictable (+) base of fill not likely in contact with any aquifer

A.2 Risk to Offsite Degradation of Surface Water Resources

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
A	Medium to High	(-) groundwater flow indicates contribution to two water courses, by relatively direct and rapid flow (+) percentage groundwater contribution to stream flow is unknown, but likely to be relatively high in at least spring and fall (-) Joshua's Creek currently flows through proposed landfill area and would likely be diverted close to the landfill edge, Joshua's Creek tributary also flows through proposed site, Joshua's Creek flows through urbanized portions of Oakville
B	Medium to High	(-) groundwater flow indicates contribution to two surface water courses by relatively direct and rapid flow (+) percentage groundwater contribution to stream flow is unknown but likely to be relatively high in at least spring and fall

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
B	Medium to High	(-) two tributary branches of Sixteen Mile Creek currently flow through proposed landfill area, and would likely be diverted close to the landfill edge, Sixteen Mile Creek flows through urbanized portions of Oakville
C	Medium	(-) groundwater flow may contribute at least seasonally to two tributaries of Joshua's Creek which traverse the site (+) percentage groundwater contribution to stream flow is unknown but is likely to be relatively high in at least spring and fall (+) the tributaries of Joshua's Creek which flow to north-east of site will likely be diverted upgradient from landfill, but tributary to southwest of site may be diverted in close proximity to fill downgradient
D	Medium	(+) groundwater flow regime likely to produce low volume and rate of discharge to surface water and provides relatively good attenuation

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
D	Medium	(+) percentage groundwater contribution to stream flow is unknown but may be locally relatively high during spring and fall (-) the northwestern portion of site is located across a surface water divide between Sixteen Mile Creek to the east and Bronte Creek to the west, both may be diverted close to the edge of a proposed landfill increasing the risk of contamination
E	Medium	(±) the groundwater flow regime is likely to produce a low volume and rate of discharge to surface water and provides relatively good attenuation, the effects of the buried channel to the south of the site, and the related granular deposits on surface water flow is unknown (±) the percentage of groundwater contribution to stream flow is unknown, but may be relatively high during the spring and fall

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
E	Medium	(+) for the most part the site appears to be located down-gradient from Bronte Creek and the flood plain of Bronte Creek, but the current proposed landfill design would place a portion of the flood plain in close proximity to the northwest edge of the landfill
F	Medium to High	(-) <u>groundwater flow contributes at least seasonally to two tributaries of Indian Creek and several other tributaries of Indian Creek arise from groundwater flow within the proposed landfill area</u> (+) the percentage of groundwater contribution to the tributaries is unknown, but is likely to be relatively high in the spring and fall and may be the only source of stream flow at other times of the year (-) at least four water courses traverse the proposed landfill site and the stream diversions will likely be close to the landfills edge

A.3 Risk of Negative Effects on Offsite Potable Water Supplies

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
A	High	(-) large number of current consumers of potable groundwater within 1 km of site (-) generally inadequate natural containment and attenuation of leachate (+) moderate potential for development of groundwater and/or surface water resources offsite within 1 km
B	High	(-) large number of current consumers of potable groundwater within 1 km of site (-) generally inadequate natural containment or attenuation of leachate (+) moderate potential for development of groundwater and/or surface water resources offsite within 1 km
C	High	(-) large number of current consumers of potable groundwater within 1 km of site

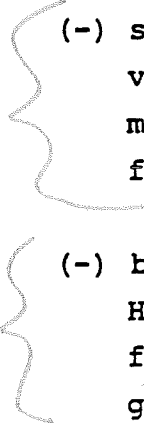
<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
C	High	(-) generally inadequate natural containment or attenuation of leachate (+) moderate potential for development of groundwater and/or surface water resources offsite within 1 km
D	Medium	(-) large number of current consumers of potable groundwater within 1 km of site (+) relatively good natural containment and attenuation of leachate (+) moderate potential for development of offsite groundwater and/or surface water resources
E	Medium	(-) large number of current consumers of groundwater and/or surface water resources within 1 km of site (+) relatively good natural containment and attenuation of leachate

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
E	Medium	(+) moderate potential for development of offsite groundwater and/or surface water resources within 1 km of site
F	Low	(+) relatively small number of groundwater and/or surface water resources within 1 km of site (+) relatively poor natural containment and attenuation of leachate although permeability distribution is unclear (+) little or no potential for off-site development of surface and/or groundwater resources within 1 km of site

A.4 Risk of Anadequate Reaction Time to Offsite Migration

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
A	High	(-) generally unpredictable inconsistent stratigraphy due to bedrock high, channel and proximity of Trafalgar Moraine (-) presence of near surface water bearing, and relatively highly permeable zones (-) nearby presence of pipeline right of way which may alter groundwater flow paths and increase speed of migration away from site
B	Medium to High	(+) relatively predictable stratigraphy, but bedrock fracture pattern somewhat unpredictable (-) presence of highly permeable aquifers near surface which may reduce breakthrough times substantially
C	Medium to High	(+) relatively predictable stratigraphy, but bedrock fracture pattern somewhat unpredictable

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
C	Medium to High	(-) presence of highly permeable aquifers near surface which may reduce breakthrough times substantially
D	Medium	(+) relatively predictable stratigraphy with generally low permeability materials (+) aquifers generally well confined by low permeability strata, but potential for relatively rapid ground-water flow in granular deposits
E	Medium to High	(+) relatively predictable stratigraphy with generally low permeability materials but presence of buried channel and granular till layer (-) aquifer may be present if connected to granular till or buried channel deposits, and groundwater flow may therefore be rapid and relatively unpredictable
F	High	{ (-) steep surface gradient and unpredictable fracture pattern in rock on local scale

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
F	High	 (-) steep hydraulic gradient and variable hydraulic conductivity may lead to rapid groundwater flow downgradient (-) bridge at King Road overpass of Highway 403 may have deep fill foundation which may affect groundwater migration

A.5 Risk of Inability to Mitigate Leachate Release

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
A	Medium	(+) relatively shallow depth to bedrock enables installation of cut off walls (+) stratigraphy may or may not allow pumping wells to stabilize a leachate plume (-) very little reliance on natural attenuation (-) once leachate enters bedrock flow direction and velocity may become highly unpredictable
B	High	(-) difficult to install cut off walls entirely into bedrock (-) stratigraphy (bedrock) only allows pumping wells in restricted joint patterns and leachate could migrate away through discreet fracture system (-) very little reliance on natural attenuation
C	High	(-) difficult to install cut off walls entirely into bedrock

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<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
C	High	(-) stratigraphy (bedrock) only allows pumping of wells tapping limited fracture system and leachate may bypass wells through a discreet fracture system (-) very little reliance on natural attenuation
D	Medium	(-) difficult to install cut off wall in 25 m deep overburden deposits (+) slower flow velocities allow smaller extent of plume to mitigate (+) predominantly downward flow to first aquifer zone, where pumping wells may be established (+) relatively high degree of natural attenuation
E	Medium	(-) difficult to install cut off wall in 25 m deep overburden deposits (+) slower flow velocities allow smaller extent of plume to mitigate

<u>Site</u>	<u>Assigned Level of Risk</u>	<u>Contributing Factors</u>
E	Medium	(+) predominantly downwards flow to first aquifer zone where pumping wells may be established (+) relatively high degree of natural attenuation
F	Medium	(-) difficult to install cut off wall entirely in bedrock (+) steep hydraulic gradient facilitate prediction of plume migration (+) reasonably well identified depth to horizontal flow zone in shale (20-30 m) (+) moderate natural attenuation capability in shale

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APPENDIX B

CORPORATE EXPERIENCE AND RESUMES

CORPORATE PROFILE & EXPERIENCE

Golder Associates is an international consulting company providing comprehensive geotechnical engineering services to the energy, minerals, transportation, civil and offshore engineering industries. The world-wide staff numbers approximately 400 of whom nearly two-thirds are highly qualified and experienced professional engineers, geologists, and hydrogeologists. Golder Associates' corporate headquarters are located in Toronto, with principal North American offices located in Toronto, Calgary, Vancouver, Atlanta, Denver and Seattle. Golder Associates has an additional 21 offices located throughout Canada, U.S.A., U.K. and Australia.

As a specialist geotechnical engineering firm, Golder Associates has provided hydrogeologic consulting services since the firm's inception in 1960.

In more recent years, Golder Associates has developed specific expertise related to the hydrogeologic and geotechnical aspects of waste disposal and management, including groundwater monitoring, contaminant migration, and groundwater chemistry.

Recent projects carried out by Golder Associates include:

Metro Toronto

Hydrogeological and geotechnical services for the 1.2 m thick 10^{-8} clay liner and leachate collection system for a 99 ha landfill. Responsible for quality control and inspection of excavation, placement and compaction of clay liner, performance monitoring program including liner-leachate compatibility testing.

M.M. Dillon Ltd. (for Environment Canada)	Hydrogeological assessment of 120 abandoned landfills on federal lands in Ontario.
Texaco Canada Inc.	Investigation of potential soil and groundwater contamination at a petrochemical refinery, Port Credit, Ontario.
Shell Canada Limited	Investigation of potential soil and groundwater contamination at a petrochemical refinery, Oakville, Ontario
Environment Canada & Ontario Ministry of the Environment	Review of co-disposal of hazardous and municipal wastes.
M.M. Dillon Ltd.	Leachate characterization study, Ridge Landfill, Blenheim, Ontario.
The Proctor & Redfern Group	Study for the design of a leachate collection system, Sault Ste. Marie, Ontario.
City of St. Catharines	Independent review of performance of municipal landfill in a former quarry with a clay liner.
Steetley Industries	Hydrogeological investigation, Dundas Brow Landfill, Ontario.
M.M. Dillon Ltd.	Evaluation of leachate generation rates, Essex County No. 3 Land- fill.
Environment Canada	Study to evaluate the use of engineered covers at waste dis- posal sites.

National Uranium Tailings
Program

Evaluation of flexible membrane
liners as long term barriers
for uranium mill tailings.

Ontario Ministry of
the Environment

Review of submissions for pro-
posed secure landfill, Model
City, State of New York.

State of New York,
Department of Law,
Environmental Protection
Bureau

Expert advice regarding proposed
investigation and remedial action
program for the Hooker 'S' Area
site.

National Uranium Tailings
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Evaluation of flexible membrane
liners as long term barriers
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State of New York,
Department of Law,
Environmental Protection
Bureau

Expert advice regarding proposed
investigation and remedial action
program for the Hooker 'S' Area
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EDUCATION B.A.Sc. (Geological Engineering), University of Windsor, Windsor, Ontario, 1977.

Excavation Dewatering Course, University of Alberta, 1983.

AFFILIATIONS Registered Professional Engineer, Ontario, Alberta, British Columbia.
Member, International Association of Hydrogeologists.
Member, Canadian Water Well Association
Member, Canadian Geotechnical Society
Member, National Water Well Association.

EXPERIENCE

1984 to date Hydrogeologist, Golder Associates, Toronto. Responsible for Project Management of a variety of physical and contaminant hydrogeological investigations with special emphasis on the Eastern Ontario region, including a review of a proposed site for the treatment and disposal of hazardous wastes and an investigation of the build-up of leachate in a municipal landfill and options for recirculation.

1981 - 1984 Senior Hydrogeologist, Hardy Associates (1978) Ltd., Edmonton. In charge of Hydrogeology Group for Hardy Associates. Responsible for mine dewatering study, and subsequent implementation at Suncor Oil Sands Division mine, Fort McMurray, Alberta; the study of pesticide migration and its mitigation at Uniroyal Chemical in Edmonton, and water supply, contaminant mitigation, and dewatering services throughout Western Canada.

1979 - 1981 Regional Hydrogeologist, Ontario Ministry of the Environment, Kingston, Ontario. Responsible for the investigation of groundwater contamination complaints, dewatering or interference complaints, review of Private Services Reports for rural subdivision applications, and landfill investigations in Eastern Ontario.

1977 - 1979 Groundwater Development Geologist, Manitoba Department of Mines, Winnipeg. Responsible for the implementation of remedial works to abate drainage problems associated with high water table conditions in the Province of Manitoba.



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V. Milligan

- EDUCATION** B.Sc., Civil Engineering, Queen's University, Belfast, 1951.
M.Sc., Soil Mechanics, Queen's University, Belfast, 1952.
Research Fellow, Purdue University, U.S.A., 1954-55.
- AFFILIATIONS** Registered Professional Engineer, Ontario, Alberta, Newfoundland and Saskatchewan.
Designated Consulting Engineer and Geotechnics Specialist, A.P.E.O.
Member, Association of Consulting Engineers, Canada.
Member, Engineering Institute of Canada and Canadian Geotechnical Society.
Fellow, American Society of Civil Engineers.
Member, Institution of Civil Engineers, U.K.
Fellow, Geological Society of Canada.
Member, International Society of Soil Mechanics and Foundation Engineering.
Past Member, Faculty of Engineering Science Advisory Committee, University of Western Ontario (1973-76).
Chairman, Associate Committee on Geotechnical Research, National Research Council, (1984 -).
Adjunct Professor, Department of Geological Engineering, University of Toronto. (1980 -).
Past President, Consulting Engineers of Ontario.
- AWARDS & PUBLICATIONS** King George VI Memorial Research Fellowship (1954-55).
Founding Editor of The Canadian Geotechnical Journal (1963-68).
R.F. Legget Award, Canadian Geotechnical Society (EIC) for achievements and contributions in the field of geotechnical engineering in Canada (1973).
Co-Editor of "Stability in Open Pit Mining", "Geotechnical Practice in Open Pit Mining". Author of numerous papers on Geotechnical Engineering topics.
- EXPERIENCE**
- 1984 to date Senior Principal, Golder Associates, involved in technical aspects of major projects and technical development. Consultant on Annacis Island Bridge, B.C.
- 1974 - 1984 President, then Chairman of Golder Associates. Consultant on Wreck Cove Hydro-electric scheme, Nova Scotia; Dickson Dam, Alberta; tailings disposal systems, Denison, Rio Algom, Elliot Lake, Ontario; Syncrude and Alsands projects, Alberta.
- 1960 - 1974 Principal, Golder Associates, Toronto. Responsible for technical control of projects covering dams for water supply and power development; waste dumps and tailings disposal; industrial developments; power and transportation tunnels; road and highway design. Projects include over 50 dams up to 200 m. in height in North America, Greece and Australia; fossil and nuclear generating facilities in Canada and Iran; road design in South America, Africa, Middle East and Europe.
- 1956 - 1960 District Engineer, then Assistant Chief Engineer, Geocon Ltd., Toronto. Engaged in foundation engineering for design and construction of projects in Canada and overseas.
- 1955 - 1956 Technical Officer, Imperial Chemical Industries Ltd. U.K., engaged in design of soda ash handling facilities and loading wharves, Cheshire.
- 1954 - 1955 Purdue University, U.S.A. Postgraduate research studies in soil mechanics and foundation engineering.
- 1952 - 1954 Assistant Engineer, James Williamson and Partners, Glasgow, engaged in fossil fuel plant design and construction.



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EDUCATION

B.Sc., Eng. (Hons), University of Southampton, England, 1967.
M.Sc., University of California, Berkeley, 1968.
Ph.D., Imperial College, University of London, England, 1972
Contaminant Hydrogeology Short Course, University of Waterloo, 1982.

AFFILIATIONS

Registered Professional Engineer, Ontario.
Member, Engineering Institute of Canada and Canadian Geotechnical Society.
Member, Institution of Civil Engineers.
Associate Member, American Society of Civil Engineers.
Member, International Society of Soil Mechanics and Foundation Engineering.
Member, National Water Well Association.

EXPERIENCE

- 1979 to date Associate, Golder Associates, Toronto. In charge of specialist hydrogeology group involved in all aspects of groundwater and contaminant migration studies. Responsible for a review of remediation of chemical disposal areas in Niagara Falls, New York; the hydrogeological investigations of potential contamination at petrochemical refineries in Port Credit and Oakville, Ontario; construction control, testing and monitoring of the clay liner at the Keele Valley Landfill, Maple, Ontario; and hydrogeological investigations of landfills, industrial sites and spills. Also responsible for all aspects of overall design, hydrogeologic appraisal and construction supervision for stage construction of tailings dams to retain 2.4 million tons of uranium tailings per year, including design of 140 ft. high tailings dam and site selection studies for disposal of 150 million tons of tailings in Elliot Lake, Canada.
- 1976 - 1979 Senior Geotechnical Engineer, Golder Associates, Toronto. Responsible for geotechnical investigations in Ontario for major sewers and tunnels, with advice during construction, remedial works at two dams, investigations at a low level radioactive waste disposal area and for a uranium refinery and the geotechnical aspects of an open pit mining project in Guatemala.
- 1975 - 1976 Head of Soil Mechanics Group, Infrastructure Engineering Division, Promon Engenharia, S.A., Rio de Janeiro, Brazil. Responsible for the geotechnical aspects of design for the foundations for the Reactor Building for Unit II of the Angra dos Reis Nuclear Power Station and a marine terminal for 300,000 dwt. Iron ore carriers.
- 1972 - 1975 Engineer, then Senior Geotechnical Engineer, Soil Mechanics Division, Promon Engenharia, S.A., Sao Paulo, Brazil. Responsible for analysis of all soil tests and recommendations for the design of two 200 ft. dams on the Rio Grande River. Geotechnical Engineer for coal storage yard on 60 ft. of soft marine clay; also the offshore wharf structures and onshore plant facilities for a marine terminal for 44 million tons of Iron ore per year in N.E. Brazil.



Golder Associates

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- EDUCATION** B.Sc., Eng. (Hons), University of Southampton, England, 1967.
M.Sc., University of California, Berkeley, 1968.
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Contaminant Hydrogeology Short Course, University of Waterloo, 1982.
- AFFILIATIONS** Registered Professional Engineer, Ontario.
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Member, Institution of Civil Engineers.
Associate Member, American Society of Civil Engineers.
Member, International Society of Soil Mechanics and Foundation Engineering.
Member, National Water Well Association.
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- 1976 - 1979 Senior Geotechnical Engineer, Golder Associates, Toronto. Responsible for geotechnical investigations in Ontario for major sewers and tunnels, with advice during construction, remedial works at two dams, investigations at a low level radioactive waste disposal area and for a uranium refinery and the geotechnical aspects of an open pit mining project in Guatemala.
- 1975 - 1976 Head of Soil Mechanics Group, Infrastructure Engineering Division, Promon Engenharia, S.A., Rio de Janeiro, Brazil. Responsible for the geotechnical aspects of design for the foundations for the Reactor Building for Unit II of the Angra dos Reis Nuclear Power Station and a marine terminal for 300,000 dwt. iron ore carriers.
- 1972 - 1975 Engineer, then Senior Geotechnical Engineer, Soil Mechanics Division, Promon Engenharia, S.A., Sao Paulo, Brazil. Responsible for analysis of all soil tests and recommendations for the design of two 200 ft. dams on the Rio Grande River. Geotechnical Engineer for coal storage yard on 60 ft. of soft marine clay; also the offshore wharf structures and onshore plant facilities for a marine terminal for 44 million tons of iron ore per year in N.E. Brazil.