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WITNESS STATEMENT AND REPORT
EVALUATION OF HYDROGEOLOGIC SUITABILITY
HALTON REGION PROPOSED LANDFILL
SITES D AND F

Prepared for: West Burlington Citizens Group
c/o Canadian Environmental Law
Association
Toronto, Ontario

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Distribution of Report

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WITNESS STATEMENT OF PAUL W. BOWEN, P.ENG.

1 QUALIFICATIONS

I am a registered professional engineer in the Province of Ontario, and practice exclusively in the areas of hydrogeology and geotechnical engineering. I am a designated Consulting Engineer, and a founding principal in the firm of Terraprobe Limited.

I obtained a Bachelor of Applied Science in Geological Engineering from the University of Toronto in 1977. After several years of practice I returned to university, and in 1984 obtained a Master of Applied Science in Civil Engineering from the University of Waterloo. The majority of my course work at Waterloo was in the Earth Sciences Department, in the area of hydrogeology.

Specific information regarding my education and professional experience is presented on the curriculum vitae in Appendix A. In summary, I have been involved in hydrogeologic and geologic investigations for environmental, mining, and civil engineering projects since 1977. I have been involved in the hydrogeologic assessment of existing and proposed municipal and industrial landfills in numerous areas of southern Ontario, including the Regions of Peel and Durham, County of Essex, and Towns of Thorold and Beamsville.

2 INVOLVEMENT WITH HALTON REGION LANDFILL ENVIRONMENTAL ASSESSMENT

The West Burlington Citizen's Group sought to obtain independent hydrogeologic consulting services, as the result of their concerns regarding the suitability of Site F for use as a municipal landfill. Terraprobe Limited has been retained by the West Burlington Citizen's Group since September 1985, in providing hydrogeologic consulting services regarding the Halton Region Landfill Environmental Assessment. This has included critical review of most of the documents and reports regarding the hydrogeologic aspects of the environmental assessment, including;

- review of hydrogeologic criteria and ranking process used during Stage 2A through 2C site selection,
- review of hydrogeologic and landfill design and operation reports prepared by various parties leading up to the hearing in May 1987,
- attendance at the hearing and/or review of transcripts regarding hydrogeologic evidence presented at the hearing.

A list of the principal documents which have been reviewed in providing advice to the West Burlington Citizen's Group, and in the preparation of this report, are presented in Appendix B.

I also undertook inspections of Site D and Site F in October 1985, January 1987, June 1987, and July 1988.

The following report presents my professional opinion with regard to the hydrogeologic aspects of the site selection process; the hydrogeologic and geologic conditions at Sites D and F; and the expected hydrogeologic impact as a result of construction of a municipal sanitary landfill at Sites D and F.

3 SITE SELECTION

During the initial stages of site selection, (Stage 2A) several criteria were identified by the Region's investigators for screening and selection of candidate sites. The Stage 2A documents indicate that the criteria of primary importance was public health and safety and that the hydrogeologic factors, ie. the potential for ground and surface water contamination, were considered as the most critical.

The site selection and consolidation report in Stage 2B (Exhibit H-11), indicated that sites with the following characteristics were to be specifically avoided:

- areas where soil thickness was not sufficient
- areas of low soil attenuation capability
- areas with steeply sloping land.

Therefore 'traditional' sites with a thick cover of low permeability soil were considered as most suitable for landfilling.

An overlay constraint mapping technique was used to produce a map of areas which were considered hydrogeologically favorable for landfilling. This map was presented as Figure 6, in Exhibit H10 (Stage 2A, Final Report and General Overview Analysis October 1983). On this map, Site F was not included in the areas which were selected as hydrogeologically suited for landfilling, as a result of the thin overburden cover, and steeply sloping ground.

However, Site F was included in the selection process when a number of pits and quarry sites were considered " - as an alternative to the use of good farm land in Halton for landfill." The use of pits and quarry sites on this basis seemed to be inconsistent with the categories originally chosen to assess the candidate areas.

These categories included public health and safety, which was based on ground and surface water impact and traffic; natural environment; social environment; cultural environment; costs; and engineering and operations. Public health and safety was considered the most important, followed by natural and social environment, which were considered to be equal to each other, but less important than safety; cultural environment, which was of less importance than natural and social environment, and finally by costs and engineering which were of least importance (Exhibit H-11).

Use of farmland for landfill was considered to be an impact on the natural environment. Therefore, it appeared that the selection of pits and quarry sites was based on placing the natural environment category ahead of the public health and safety category. This would appear to be inconsistent with the site selection criteria, which considered public health and safety to be the most important category.

At this stage, it was recognized "..pits and quarries candidate areas may present rather distinct hydrogeological and operating characteristics for sanitary landfilling which must be considered on their own merits." It was suggested that additional attention would have to be paid to the hydrogeology of these sites, and to the engineering and management of leachate. Three constraint categories were included for the pits and quarry site only, and these included leachate generation, leachate collection and leachate treatment. It would seem that this was based on the consideration that escape of leachate from the quarry site may be of greater concern, since they are less suitable for landfill than candidate non-quarry sites.

At the stage 2B level, the leachate collection and generation criteria seemed to be based mainly on the concept of drawing the water table down around the quarry to provide a trap and prevent off site flow. The ability of the geologic environment to provide a hydraulic trap at the candidate sites was based only on limited hydrogeologic data, including a discussion with site operators regarding the volume of water pumped from the quarries. It is noted that at this stage most of the site F area was undisturbed land and had not been developed as an active quarry, although portions of it were licensed as such.

At the Stage 2C site selection level, Site F had been included in the selection process along with five non-quarry sites. With respect to hydrogeologic assessment criteria, site F appeared to fare worse than site D, in all aspects except for current use of the groundwater resource:

Criteria and Judgement	Site D	Site F	Comment
Attenuation capability (soil better than rock)	thick soil	rock	F worse
Geologic Complexity (simple better than complex)	uniform till with sand layers	fractured rock	F worse
Overburden thickness (thick overburden better than rock or thin overburden	Thick overburden	rock/thin overburden	F worse
Complexity of flow system (simple better than complex)	recharge	recharge and discharge	F worse
Type and distribution of aquifers (no use of aquifer or poor aquifer best)	resource poor, some use	resource poor, serviced with municipal piped water	F better

Despite site F faring worse in each category except for type and distribution of aquifers, it was considered to be better suited for landfilling from a hydrogeologic viewpoint than Site D.

In summary, there appears to be a number of inconsistencies with regard to the selection of Site F based on hydrogeologic criteria. Based on the hydrogeologic date which was available at the stage 2A through 2C selection process, and the prevailing state of knowledge regarding contaminant transport in fractured rock systems at the time of site selection, it is our opinion that Site F should not have been selected as a more suitable candidate site than Site D.

4 DISCUSSION OF SITE F

4.1 Geologic and Hydrogeologic Conditions

There have been a large number of hydrogeologic assessments conducted for Site F and the adjacent Bayview and Burlington Landfill sites. This includes studies presented by Cherry and Lush, Morrison Beatty, Hewetson, Gartner Lee, and Trow Hydrology Consultants Ltd.

As is noted on Page 7 of exhibit H40, all of the investigators present somewhat different views regarding the hydrogeologic conditions in the vicinity of Site F. It is our opinion that the Trow Hydrology Consultants Limited (THCL) investigation of the Site F area, as presented in exhibit H40, represents the most comprehensive study of the area. Specifically, it is based on a larger data base (larger number of sampled borings, in situ tests of permeability, and extensive sampling of groundwater quality), when compared to previous investigations by others.

We undertook a detailed review of the factual data, including plotting of all of the permeability, fracture, RQD and tritium data to compare with the THCL interpretation. Upon detailed examination, it became apparent that we could not support the THCL interpretation due to inconsistencies between the factual data and the interpretation.

During cross-examination, Mr. Sobanski and Mr. Beechinor presented a working drawing (exhibit H-220) which was considerably different than the idealized interpretations presented in the THCL report. This working drawing contained factual data from the study (rock fracture logs, tritium, permeability testing and the like), and presented as THCL's hydrogstratigraphic interpretation of the site. It is our opinion that exhibit H-220 was not consistent with the geologic or hydrogeologic data presented in the THCL report.

Subsequent presentations made by Conestoga Rovers Associates (CRA) in exhibit B-617 (Figures B-3.3 and Figure B-3.6) also indicated that there is poor correlation between the THCL interpretation of the site and the available borehole logs and results of in situ testing.

Thus, based on a detailed review of the factual information, we could not support the stratigraphic and hydrostratigraphic interpretation presented by THCL on Figures 2, 4, and 6 of exhibit H-40, and exhibit H-220.

Computer modelling of the flow system was conducted by THCL, using the FLONET model presented in exhibit H-40, and the subsequent 'better fit' model presented in exhibit H-221. These models were used to provide a 'better understanding of the existing groundwater flow system...., flow paths, infiltration/discharge occurrences and rates, and potential contaminant migration paths'. We note that the calibration of these models is based on providing a reasonable fit to the hydraulic head data (water levels) for the site. The models represent a non-unique solution to the data, meaning that many different interpretations of stratigraphy and permeability can be used to provide a similar fit to the data. Since we do not agree with the stratigraphic interpretation provided by THCL, it is our opinion that the flow system and flow paths represented by the models must be viewed with caution. In particular, the delineation of the extent and location of discharge zones and the possible contaminant flow paths may be subject to considerable error. This is illustrated in the FLONET modelling conducted by CRA and presented on Figure C.4.2 of exhibit B-617, which illustrates a much larger zone of discharge, while maintaining a reasonable fit to the head data.

Dr. Charlesworth (exhibit M-471) suggested that while the geology of the site was complex in detail, it was reasonably simple on a regional scale. His report suggested that the flow system consisted of an upper active zone, where groundwater movement was rapid and flow paths relatively short; and a deeper inactive or sluggish zone, where groundwater flow was very slow and flow paths were much greater in length.

Mr. Hodgson presented a similar concept during his cross-examination of Mr. Petrie. These discussions were presented in Volume 117 of the transcripts and on exhibits H-653, H-663, H-664 and M-677. In summary, it was suggested that two distinct flow systems could be described within the shale bedrock beneath the site. The first consisted of an upper active zone, which was characterized by low to moderate chloride levels, and high tritium levels. The existence of this zone was also inferred at the adjacent landfills, where the presence of leachate was implied based on relatively low levels of various organic parameters, including chlorobenzene.

The second system comprised a lower sluggish flow system that was characterized on the basis of saline groundwater (high chloride), and low tritium values.

It is our opinion that this latter concept of an active and sluggish flow system is a better representation of the site conditions. We note that the most compelling evidence of this flow system is the groundwater quality data. Based on this data, it would appear that the upper active zone may be on the order of 15 to 20 m of thickness, although it may be quite variable.

However, the results of in situ testing of the hydraulic properties of the rock, including the packer, Hvorslev and pump tests, do not provide an interpretation which is consistent with the groundwater quality data. Therefore, the hydrogeologic and hydrostratigraphic characterization of the site is based primarily on indirect evidence, ie. results of the water quality testing. This is contrary to the method generally used to characterize site conditions, whereby the geologic data gained from borings and in situ testing are used to provide an understanding of site hydrostratigraphy.

It is our opinion that the difficulty in characterizing Site F by conventional means is the result of several factors;

- Site Lithology. The geologic material beneath the site consists predominantly of shale. Flow through the shale is primarily through fractures. On the basis of visual examination it is very difficult to assess the hydraulic properties and groundwater flow which may occur through the fractures, since the fracture aperture and condition (ie. clay filling) is disturbed during the drilling process. Conversely, at a conventional site in porous media, the lithology is much more readily characterized. Areas of significant groundwater transmission (such as sand and gravel) can easily be visually identified from areas of low groundwater transmission (clays and glacial tills)

Interpretation of Hydraulic Properties of Fractured Rock. The nature of groundwater flow systems through fractured rock (groundwater flow directions and velocities) are very difficult to determine except on a large scale. This is largely due to the difficulty in determining the hydraulic properties (permeability) of the fracture system, as well as the extent, orientation and aperture of the fractures. Interpretation of these properties is exacerbated by the lack of analytical methods to assess these hydraulic properties. The analytical methods which have been developed to assess the results of Hvorslev tests, packer tests and pumping tests are generally based on analysis which are intended for porous media. Therefore, these analyses may not be directly applicable to fractured rock, and may lead to difficulties in the interpretation and calculation of hydraulic parameters. The interpretation is most tenuous when the scale of the testing is small, and does not affect a large mass of the rock. As noted by Blackport et al (ex. WB-226) the direction and velocity of groundwater flow in fractured rock is difficult to assess and may not fully correspond with the direction indicated by gradients and head data.

4.2 Contaminant Transport and Groundwater Flow Paths

As noted previously, the characterization of the groundwater flow system at the site is based largely on the results of groundwater quality analysis. It is our opinion that such an interpretation does not provide as complete or direct an understanding of the flow paths and the hydrostratigraphy of the site, as would be obtained if the site could be characterized by separate strata, each with individual hydraulic properties and groundwater flow systems.

For example, if the hydrostratigraphic interpretation presented by THCL in exhibit H-40 could be supported by the available data, then a reasonable basis could be provided for assessing the location and extent of any impact resulting from the site. However, a characterization which is based on indirect evidence, such as groundwater quality, may not permit this type of interpretation. Therefore, it is difficult to provide a clear assessment of the location and nature of any impact from the site.

It is our opinion that leachate which escapes the site will enter the shallow active groundwater zone, which has been described previously. Within this zone, it is expected that groundwater discharge within hundreds of metres of the site, into adjacent creek valleys and surface water courses in the immediate vicinity of the site, as well as to the marsh noted to the south of Highway 403. We note that the creeks in the area ultimately flow through the Aldershot residential community. The precise size of the discharge zone cannot be determined with certainty from the existing data.

Groundwater modelling presented by Dr. Rowe in exhibit M-440 showed the significance of diffusion to the matrix as an attenuation mechanism in the shale bedrock. The model also indicated that significant attenuation would occur for a relatively wide range of aperture widths and spacings, hence, attenuation was not sensitive to these parameters.

However, as identified in exhibit M-440, the model is generic in nature and does not specifically account for the geology of the site. Rather, it provides a general interpretation, as it is based on a uniform condition of fracture spacing and orientation. The modelling also indicates that for widely spaced fractures there is little opportunity for diffusion, and contaminant velocities may be relatively high. Therefore, it is important to identify if such fracture systems are present in the vicinity of the site, as they convey small though significant volumes of unattenuated leachate rapidly from the site (Case 1, Figure 4, exhibit M-440).

There has been considerable discussion regarding the infiltration rate beneath Site F. THCL presented a range of approximately 12.7 to 22.5 mm per year in exhibit H-40 (Page 74) for existing site conditions, without the landfill in place. Infiltration rates when the landfill was in place, with a mound of a 10 m height, were calculated as 22.6 mm per year. CRA, based on a conceptualization of the site presented in exhibit B617, estimated that the infiltration of the site may be in the order of 50 to 100 mm per year.

It is our opinion that the infiltration at the site under current conditions is likely on the order of 10 to 20 mm per year, which is similar to the value predicted by THCL. This value is supported by a river basin study for the Oakville and Sixteen Mile Creeks (Appendix C); and the extent of the leachate plume which is currently observed at the adjacent Burlington Landfill site.

The results of the river basin study are based on a review of well data and an interpretation of the hydraulic properties and gradients within the shale bedrock. It is recognized that the river basin study includes areas which are underlain by a different geologic materials, primarily the Halton till. Nonetheless, it is our opinion that the results of the study are a reasonable estimate of the existing groundwater recharge in the vicinity of Site F.

As presented by Mr. Hodgson in cross-examination of Mr. Petrie (Volume 113) the use of recharge values in excess of 10 to 20 mm per year would lead to the expectation that a leachate plume could be found for a considerable distance beyond the existing Burlington site. This has not been observed.

THCL calculate a net discharge of approximately 10,000 cu.m. per year of leachate from the proposed Site F (exhibit H-40). This represents the volume of leachate which will escape the site and underdrain system. It is based on the infiltration rates calculated using the original FLONET model (approximately 22.6 mm per year with the landfill in place).

While we are not in agree with the method used to arrive at this infiltration rate, we are in agreement that the numerical value of infiltration is about 10 to 20 mm per year. Accordingly, it is our opinion that the leachate escape from the site will be on the order of 10,000 cu.m. per year.

We note that this escape of leachate will occur under the design and operating conditions proposed by THCL, which includes installation of perimeter and underdrain systems. In the event of plugging or failure of either system, then additional leachate escape will occur unless remedial work is undertaken. This suggests that the underdrain system is an essential part of the landfill design, which must be maintained and operated for the contaminating lifespan of the landfill.

4.3 Groundwater Resources in Aldershot Area

A survey of existing private wells in the Aldershot area was conducted in conjunction with the West Burlington Citizen's Group. The purpose of this survey was to determine the location of existing wells in the area and to collect water samples for water quality analysis.

The results of our well survey indicate that there is some existing use of groundwater resource in this area. The wells appear to be shallow and draw water from sand strata or sand lenses within the overburden material. The location of the wells, and results of water quality analysis with respect to chloride and sulphate are summarized on the accompanying Table 1 and Figure 1. It is noted that these have been presented as exhibit WB227 during the course of the hearing. At several locations, including 729 and 1047 Plains Rd., and 1067 King Road, the well is the only source of water supply and the residents indicate they have not connected to the municipal supply.

In contrast to the groundwater in the immediate vicinity of Site F, the chloride levels are relatively low, ranging from about 9 to 100 mg. They generally meet the Ministry of Environment drinking water guidelines with respect to this parameter. These wells indicate the presence of a limited but good quality groundwater resource in the Aldershot area.

4.4 Impact of Leachate

Most of the leachate which escapes the collection system is expected to discharge within hundreds of metres of the site, to the ground surface and the surface water system. A small percentage of the leachate will travel downward and enter the deep flow system and ultimately discharge at a much greater distance from the site, in the vicinity of Lake Ontario. It is very difficult to precisely quantify the amount of leachate which may enter the deep flow system. However, based on the very sluggish nature of this flow system, as evidenced by the low tritium and high chloride values, it is expected that the volume leachate entering this system will be much smaller, and perhaps less than 10 percent of total leachate discharge from the site.

Since most leachate will travel within the upper active flow system, it is considered important to more precisely delineate the depth and extent of this system in the vicinity of the site. This is important since any perimeter collection drain which may be constructed must effectively penetrate the full depth of the active flow zone, in order to intercept most of the leachate flow.

It is not expected that the leachate discharge from the site will cause a measurable effect on water quality in private wells located down gradient of the site, in the Aldershot area. This is the result of several factors including:

- the relatively low salinity of water in this area, as compared to the underlying high salinity of water in the shale. This suggests that there is relatively little mixing of the deep and shallow flow systems. This is likely the result of the different densities of low and high salinity waters which causes the low salinity of water to 'float' on top of the high salinity water. This equilibrium is maintained by infiltration by fresh rain water.

- the very long flow path and significant attenuation which is expected to occur between the site and the nearest well.

While leachate egress from the site may not pose an immediate health and safety concern, there are several other concerns which must be considered. Firstly, the predictability of the site, with respect to the location and extent of contamination, is expected to be poor. This is the result of the poor definition of the flow paths and geology on a small scale, ie. within the immediate vicinity of the site. Secondly, it appears that the monitoring of leachate egress from the site must be based on organic parameters, as a result of the high salinity and poor ambient groundwater quality. This type of monitoring program is not conventional, and requires more stringent analytical procedures and data interpretation.

Nonetheless, it is emphasized that there will be a definite off site impact, as there will be an escape of leachate from the site. While this impact may not affect the existing groundwater resource it may have some measurable affect on surface water courses in the area which subsequently flow through the Aldershot area. Further, it will represent an uncontrolled source of contaminant loading to the environment.

The current philosophy of waste management, such as presented by the Ministry of Environment in the MISA program, is to apply the best available technology to reduce contaminant discharge from all sources to the lowest possible level. This consideration is not based on strict public health and safety considerations in the immediate vicinity of a source, but rather is based on the reduction of the overall loading of contaminants to the environment as a whole. The best available technology for reduction of contamination at Site F, would include:

- the installation of a low permeability liner which may reduce the amount of leachate discharge 50 percent, based on THCL calculations in exhibit H-40, and,

- an extensive perimeter collection system, to cut off seepage through the upper active flow zone. We note that it will be difficult to assess the effectiveness of such a system unless the thickness of the upper zone is determined, or

- the installation of purge wells as part of the operating and design of the site, to ensure containment of groundwater flow through the active upper zone.

It is our opinion that incorporation of the above measures in the design is appropriate, based on minimizing the contaminant loadings to the environment. The need for this reduction of contaminant loading is also supported by the lack of predictability of the site, as well as the unconventional methods required for the monitoring of the site.

5 DISCUSSION OF SITE D

5.1 Geologic and Hydrogeologic Conditions

All investigators (THCL, Conestoga Rovers & Associates, and Dr. Charlesworth) are in agreement with the general stratigraphic characterization of the site, as presented by THCL. In summary, this interpretation includes delineation of the following zones;

- weathered upper till
- unweathered upper till
- lower till
- upper granular unit
- lower granular unit
- shale bedrock
- thin silt bed

The broad agreement concerning site lithology occurs since Site D consists largely of soil materials which can be readily identified on a visual basis.

There is some disagreement with respect to the horizontal continuity of the granular units, the permeability of the various strata, and the groundwater gradients. It is noted that these disagreements are generally more a matter of degree than concept at this site. It is our opinion that this again emphasizes that the stratigraphy at Site D is much more readily characterized than that of Site F, and suggests that additional investigation can be conducted to characterize site stratigraphy to the satisfaction of all parties.

5.2 Contaminant Transport

Firstly, it is important to recognize that the hydraulic trap concept proposed by THCL will prevent the off site migration of contaminants. While there is a large degree of discussion regarding the engineering details and long term operating characteristics of the proposed hydraulic trap system, it is recognized by all parties that a properly functioning hydraulic trap would effectively prevent off site migration of contamination.

It is also important to note that all investigators identify the same critical contaminant pathway for the site. This pathway consists of downward migration through the upper and lower till units, followed by lateral migration, through the upper granular unit. This understanding and characterization of the critical flow path suggests that differences of opinion regarding the continuity and permeability of the various strata are of less importance than at Site F, since a more assured monitoring and contingency plan can be implemented.

The results of a coupled modelling exercise, as presented by THCL, suggest that contamination would first appear approximately 60 years following failure of the hydraulic trap (Figure 19 of exhibit H-39).

Dr. Rowe (exhibit M-442, pg 6) indicated that off site migration through the upper granular unit may occur in a much shorter time frame, ranging from about 6 to 58 years, depending on the failure scenario which is considered. It is our opinion that cases 6 to 10 (pg. 27, exhibit M-442), which suggest off site migration after 6 to 21 years, are based on parameters which are overly conservative. Specifically, they consider a total failure of the collection tiles, with subsequent mounding to elevations of about 4.8 to 15 m above the existing water table. It is our opinion that the combination of these two events would be readily apparent to the landfill operators, and that suitable contingencies could be implemented to lower the mound and/or collect leachate from the upper granular unit.

Neglecting these cases, a range of 20 to 58 years is calculated for off site impact. Most of the remaining cases are based on assumptions of partial failure of the system. Again, it is our opinion that these time frames are ample to identify a partial failure of the trap, and implement suitable contingencies.

Nonetheless, the modelling presented by Dr. Rowe suggests the importance of maintaining and monitoring the efficiency of the collection system, in order to ensure that the trap functions as designed.

CRA presented several modifications to the THCL design to address these concerns (exhibit B-618). This included changes to the layout of the underdrain system, and installation of a granular drainage layer beneath the landfill. It is our opinion that these design modifications are appropriate to facilitate long term operation of the trap.

It is our opinion that in the event of failure of the hydraulic trap, leachate migration from the site can be much more readily predicted than that of Site F. This is the result of several factors including;

- better definition of site geology and therefore of the contaminant pathway,
- a higher degree of predictability of contaminant transport within porous media, as compared to fractured media,
- the relatively slow (period of tens of years) rate at which contaminant migration will occur, which will ensure that adequate time is available to effect appropriate contingency measures
- better ambient groundwater quality which would permit use of conventional monitoring parameters.

In the event of failure of the trap, it is our opinion that several different types of contingency measures could be implemented at the site in order to ensure complete containment of leachate. These would include:

- purge wells within the upper granular, and/or

- large diameter pumping wells installed within the waste in order to lower the leachate levels and maintain the trap or reduce the rate of leachate egress.

Evidence was presented that some contaminant egress may occur as a result of diffusion from the base of the landfill, even with the hydraulic trap operating and in place. We are in agreement with the evidence presented by Mr. Petrie on exhibits B-642 to B-644, which indicate diffusion profiles beneath the landfill. These indicate that a very long period of time is required (approximately 140 to 170 years) to achieve breakthrough from the till into the upper granular unit. These calculations are based on the very conservative assumption that the input of contaminant will not decline with time. We are in agreement Mr. Petrie and Mr. Sobanski that there will be reduction of contaminant concentration with time. Therefore, diffusion will occur back into, or toward the landfill as a result of reducing concentrations at the source. Thus, diffusion outward from the landfill is not considered to be a significant contaminant pathway at this site.

Finally, it is noted that the primary contaminant pathway considered for the site (ie. the upper granular unit) may not be continuous off site, and may not provide direct connection to neighboring water wells. The extent and continuity of this unit can be readily explored by additional test drilling and pump testing.

In conclusion, it is considered that with appropriate monitoring operating contingency plans complete containment of contaminants within the Site D boundaries can be assured.

6 CONCLUSIONS

The following conclusions are based on our review of the data and evidence presented with regard to Sites D and F.

Stratigraphic conditions at Site D have been adequately characterized and the contaminant flow path has been identified. Using the hydraulic trap concept, the landfill can be designed so that no off site migration of contaminants will occur. In the event of failure of the trap, or other unforeseen circumstances, then off site migration of contamination is expected to be slow and predictable. Migration and contaminants can be detected by conventional monitoring methods using inorganic indicator parameters such as chloride.

In the event of failure of the hydraulic trap, there is ample time to institute proper remedial control measures. The proposed remedial measures, consisting of purge wells in the upper granular unit, are considered to be a proven and suitable method to prevent off site migration.

Stratigraphic conditions at the Site F are not as well characterized as those at Site D. This is the result of lithology of the site (fractured shale bedrock) and the inherent difficulty in predicting the direction and velocity of groundwater flow on a small scale basis in a fractured media.

It is our opinion that there will be off site migration of leachate from Site F, using the site design proposed by THCL. The volume of leachate escaping from the site will likely be in the order of 10,000 cu.m. per annum. The pathway for leachate escape from the site is known only in a very general sense. It is expected that most of this leachate will discharge to the ground surface and surface water courses within hundreds of metres of the site. These water courses subsequently flow through the Aldershot residential community. This leachate discharge would represent an intentional, uncontrolled source of contaminant loading to the environment. The design of the site could be altered to reduce this discharge by installation of a low permeability liner, and a purge well system or extensive perimeter collection system.

In conclusion, it is our opinion that Site D presents a more suitable and predictable hydrogeologic environment for landfilling than Site F.

Respectfully Submitted,
TERRAPROBE LIMITED

Paul W. Bowen, P.Eng.

TABLE 1

SUMMARY OF WATER WELL SAMPLING
BURLINGTON - SITE 'F'

Well Number Address Owner	THCL No.	Well Use	Chloride	Sulphate	Comments
1 1047 Plains Rd Schmaltz	..	domestic	25	37	no municpal supply uses for everything
2 729 Plains Rd Alaouzk	..	commercial	62	92	no municipal supply use for everything
3 683 Plains Rd Bowen	43hc	domestic	28 (75)	65 (87)	uses for drinking
4 661 Plains Rd Bowen	..	domestic	51	60	uses for drinking
5 661 Plains Rd Bowen	..	domestic	51	60	duplicate sample
6 1102 King Rd Strathcona Garden Centre	..	commercial	100	32	property sold
7 1870 King Rd Robertson	..	residential	413	123	new well, in rock 35 m deep
8 1865 King Rd Lusho	..	residential	10	86	cistern, collects surface water
9 1067 King Rd Wilson	37hc	residential	65 (59)	59 (62)	no municipal supply
10 589 Kingswood Pl Klodt	39hc	residential	62	70	gardening supply
11 1077 Clearview Langton	..	residential	115	73	uses for everything

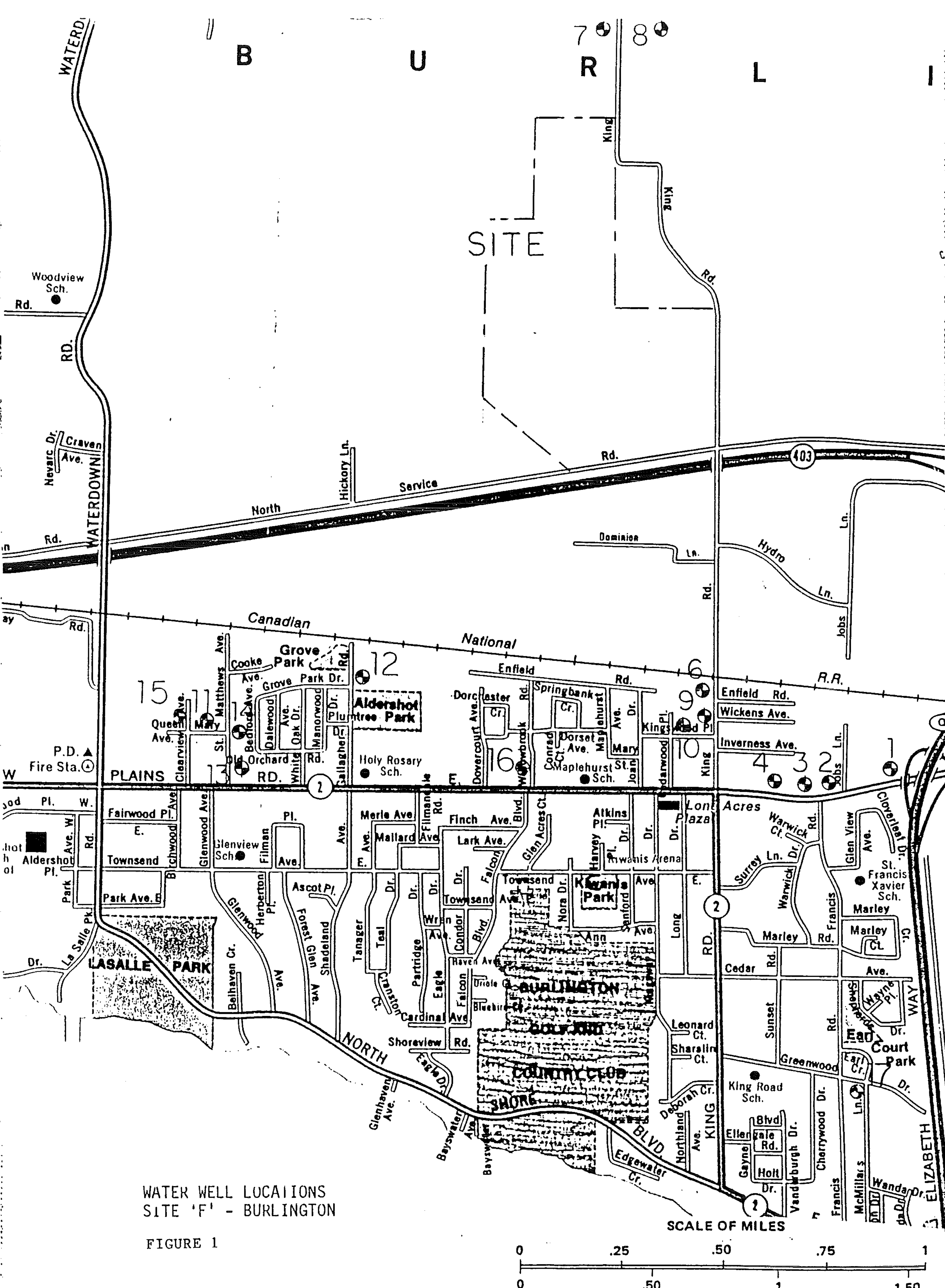
TABLE 1

SUMMARY OF WATER WELL SAMPLING cont'd
BURLINGTON - SITE 'F'

Well Number Address Owner	**THCL No.**	**Well Use**	**Chloride**	**Sulphate**	**Comments**
12 1107 Gallagher Van Duyvoorde	..	residential	51	59	uses for everything
13 1029 St. Matthew Tardiff	..	residential	68	75	drinking
14 1061 St. Matthew Dalloway	..	residential	62	75	drinking
15 1072 Clearview Cupito	..	residential	39	41	drinking
16 1028 Willowbrook Garlow	42hc	residential	35	58	--
17 1018 Greenwood	..	residential	9	30	--

Notes

(i) All sampling conducted June 27, 1987
(ii) All analyses performed by Barringer Magneta Ltd, Rexdale, Ont.
(iii) Refer to accompanying figure for locations.
(iv) THCL No. refers to Trow Hydrology Consultants Ltd well number, Appendix 9, and, Drawing 2.



WATER WELL LOCATIONS
SITE 'F' - BURLINGTON

FIGURE 1

APPENDIX A

CURRICULUM VITAE

PAUL W. BOWEN, P.ENG.

CURRICULUM VITAE

PAUL W. BOWEN, P.Eng.

EDUCATION

B.A.Sc., University of Toronto, 1977
Department of Geological Engineering and Applied Earth Science

M.A.Sc., University of Waterloo, 1984
Department of Civil Engineering
(Hydrogeology and Geotechnical Engineering)

AFFILIATIONS

Registered Professional Engineer, Province of Ontario
Designated Consulting Engineer, Province of Ontario
Member, Association of Groundwater Scientists and Engineers
Member, Engineer Institute of Canada
Member, Canadian Geotechnical Society
Member, American Society of Civil Engineers
Member, International Society of Engineering Geology
Member, Geological Advisory Committee, Sir Sanford Fleming College
Lecturer, Sir Sanford Fleming College

PROFESSIONAL EXPERIENCE

1984 to date
Terraprobe Limited Brampton, Ontario

Vice-President responsible for coordination and technical direction of hydrogeologic and geotechnical investigations for civil, industrial, environmental, and mining fields. Areas of involvement in hydrogeology include site selection for municipal and hazardous waste management projects, evaluation of groundwater quality and contaminant movement, modelling of contaminant migration, groundwater resources development, and ground water control and dewatering. Areas of involvement in geotechnical engineering include site investigation and terrain analysis, foundations and settlement analysis for structures, design of earth embankment dams and lagoons, analysis of slope stability.

1982 to 1984
Golder Associates Mississauga, Ontario

Hydrogeologist/Geotechnical Engineer, responsible for technical adminstration of projects for hazardous and municipal waste management facilities in Canada and U.S.A., including design of monitoring well systems, supervision of groundwater sampling programs, leachate characterization programs, assessment of geochemical behaviour, attenuation and transport of contaminants in the groundwater system. Responsible for studies of hydrogeologic impact of quarry operations, prediction of groundwater inflow into underground mines and open pits and recommendations for groundwater control. Analysis of infiltration through landfill covers, and assessment of leachate production rates. Geotechnical studies of stability of contaminant dykes.

1979 to 1981
Golder Associates Mississauga, Ontario

Geotechnical Engineer, responsible for supervision of major geotechnical investigation of tailings management area of uranium mill, design of tailings containment dams, analysis of dynamic stability, assessment of borrow materials, laboratory testing of low permeability dam core materials. Responsible for geotechnical investigations and recommendations for remedial measures for several slope failure/movement in Southern Ontario, and dam failure in northern Ontario.

1977 to 1979
Bruce A. Brown Associates Limited Toronto, Ontario

Geotechnical Engineer, involved in numerous field investigations for building foundations, aggregate resource surveys, septic system studies, municipal water well development and pumping tests.

SELECTED PROJECT EXPERIENCE

Study of over 120 abandoned landfill sites in Ontario as part of a federal government inventory. The study comprised a detailed review of local and regional hydrogeologic conditions, interviews with former site operators and local residents, and detailed site inspections. A priority rating system was established to indicate the relative impact and hazard of each site. The highest priority sites were chosen for later, detailed investigation.

Development of sampling program for an industrial waste disposal facility near Chatham, Ontario. Specialized stainless steel monitoring wells were installed through closed former lagoons which once received liquid wastes. The wells were specially cleaned and prepared to permit sampling to characterize leachate composition for design of treatment facilities.

Study of migration of cyanide waste from an industrial disposal area in Windsor, Ontario. Monitoring wells were installed and soil samples were obtained from the vicinity of a former waste disposal area which was alleged to contain cyanide wastes. Detailed monitoring indicated that cyanide wastes were not present in the soil and groundwater in the vicinity of the site.

Hydrogeologic investigation for a major industrial waste processing and disposal facility near Toledo in Northern Ohio. The investigation included installation of over 30 monitoring wells to assess the nature and source of possible ground water contamination at the site; detailed sampling and water quality analyses for priority pollutants and volatile organic compounds in the parts per billion range; meetings and presentations to state and federal agencies regarding proposed monitoring programs and remedial measures for site upgrading; assessment of stability of lagoons and dykes containing hazardous waste; recommendations for closure of operating lagoons and consisted of detailed investigation of cover thickness and leachate levels within the landfill; monitoring of leachate breakout location and volumes adjacent to the landfill; and modelling of predicted leachate production rates based on a water balance model. Recommendations were presented for detailed design and installation of a lysimeter beneath the cover to monitor rates of infiltration.

Hydrogeologic assessment of existing municipal landfill located in a former limestone quarry on the Niagara Escarpment, near Beamsville, Ontario. Included detailed drilling and sampling program to determine site geology/hydrogeology; installation of monitoring wells to sample ground water quality, and establishment of key surface water monitoring points. Detailed recommendations were presented regarding limitation of waste types accepted at the site, and probable future impact of the site.

Hydrogeologic assessment of municipal landfill near Thorold, Ontario. The study included installation of monitoring wells to sample groundwater quality, and detailed sampling of surface water courses in the vicinity of the site, to determine possible impacts of leachate migration from the site. Recommendations were presented for a long term monitoring program for the site, and the possible effect of the site on ground and surface water resources in the area.

Assessment of the hydrogeologic impact of a proposed quarry operation in the Niagara Escarpment was studied. The study included review of available geologic, topographic, and water well data, to assess the effect of the quarry on local water supplies, and on local wetland areas which had been designated as environmentally sensitive. The possibility of regional lowering of groundwater levels, stream capture, and deterioration of water quality as the result of pumping from the quarry were studied.

Assessment of groundwater control requirements for uranium mine feasibility study near Midwest Lake, Saskatchewan. The potential for large inflows of water at high pressures were a key element in the feasibility of the mine, due to the highly mechanized mining methods proposed, the marginal economics of the deposit, and the remoteness of the site. The expected groundwater response during mining was assessed using several analytical models developed to suit the unique geologic setting and mining procedures. Recommendations were presented for appropriate groundwater control measures, including shaft freezing, deep wells, and grouting.

Study of mine water inflows for gold mine in North Quebec. An underground pumping test was conducted during the development stages of the mine, using existing drillholes and pump capacity, to assess the hydraulic properties of the bedrock. A simple analytical model was developed to predict groundwater inflows during mine development and operation, and to determine the rate of depressurization for use in rock mechanics stability studies. Recommendations were also presented for appropriate pumping capacity for the mine.

Investigation of the properties of glacial till materials for use as low permeability cores for containment dams for an active uranium tailings facility in Elliott Lake, Ontario. A detailed parametric study of the effect of water content, degree of compaction, and overburden pressure on the permeability of the soil was undertaken. Recommendations and design specifications were produced for construction of the dam cores.

Evaluation of groundwater availability for Domtar industrial process supply, Brampton, Ontario. A review of available hydrogeologic records and geologic data was conducted, and a test well was drilled. Aquifer properties and water quality were assessed by means of a long term pumping test. Based on the results of the study, recommendations were provided for augmentation of the existing piped municipal supply with groundwater.

Evaluation of groundwater availability for residential subdivision near Orangeville, Ontario. Three test wells were and subjected to an extended pumping test. Recommendations were provided for optimum pumping rates, based on analysis of aquifer properties and prediction of drawdown in surrounding wells.

Evaluation of groundwater availability for residential retirement community near Stroud, Ontario. The availability of groundwater supply for an 1800 unit retirement community requiring a 500 igpm was supply investigated. Three production wells of about 90 m depth were subjected to an extended pumping test. Recommendations were provided for pumping efficiency of each well, and effect on operating costs. Based on the aquifer properties, recommendations were made regarding safe long term pumping rates and peak pumping rates to meet short term demand. Technical support was provided for a Permit to Take Water Application.

Site hydrogeologic characterization for proposed residential subdivision near Georgetown, Ontario. Terrain analysis was conducted to assess the suitability of a 22 ha. property for development using individual wells and private waste disposal systems. Recommendations were presented regarding the required lot sizes, local groundwater quality, requirements for water treatment, and measures to minimize contamination of the aquifer.

Evaluation of groundwater availability for municipal well, Blind River, Ontario. A terrain analysis was conducted to assess the availability of groundwater supplies for a proposed housing development. Based on geologic data, a site was selected for a test and development well to utilize induced infiltration from Lake Huron in order to maximize well capacity. The well was pump tested and was found to be capable of providing over 900 litres per minute.

Site evaluation for development ofindustrial subdivision on former landfill area, in Mississauga, Ontario. A detailed subsurface investigation was undertaken in a former ravine site which had been landfilled over a 20 year period. The investigation identified the extent and nature of the landfilled materials, and the requirements for fill removal to permit re-development of the site as an industrial subdivision. Requirements for methane gas venting and protection systems for structures were identified, and construction requirements for site grading, road and sewer installation, and placement of foundations in deep fill areas were provided. Recommendations were presented for phased development/removal of fill to ensure economic viability of project, while maintaining environmental safety.

APPENDIX B

SUMMARY OF PRINCIPAL DOCUMENTS REVIEWED

SUMMARY OF PRINCIPAL DOCUMENTS REVIEWED

- Conestoga Rovers Associates, February 1988 - Evaluation of Halton Region Landfill Technical Study Site F Burlington Hydrogeologic Report

- Conestoga Rovers Associates, February 1988 - Evaluation of Halton Region Landfill Technical Study Site D Burlington Design and Operation Reports

- Conestoga Rovers Associates, February 1988 - Evaluation of Halton Region Landfill Technical Study Site D Milton Hydrogeologic Report

- Conestoga Rovers Associates, February 1988 - Evaluation of Halton Region, Technical Studies Site F Design and Operations Report

- Gartner Lee Limited, December 1986 - Burlington Regional Landfill Plume Delineation Program Report

- Gartner Lee Limited, March 1986 - Burlington Landfill, 1985 Monitoring Report for the Regional Municipality of Halton

- Gartner Lee Limited, October 1984 - Burlington Landfill 1985 Monitoring Report for the Regional Municipality of Halton

- Gartner Lee Limited, March 1988 - Halton Regional Landfill Burlington 1987 Monitoring Report

- Geocon, October 1987 - Review of Hydrogeologic Report Site D Milton Proposed Landfill Region of Halton

- Geocon, October 1987 - Review of Hydrogeologic Report Site F Burlington Proposed Landfill Region of Halton

- Trow Hydrology Consultants Limited, September 1986 Halton Region Landfill Technical Report, Site D Milton

- Trow Hydrology Consultants Limited, September 1986 Halton Region Landfill Technical Report - Site F Burlington

- Morrison Beatty Limited, November 1981 - Phase III Hydrogeologic Investigation National Sewer Pipe Limited Landfill Site Burlington

- Rowe, R. Kerry, October 1987 - Examination of the Potential Impact of Groundwater Quality of the Proposed Halton Landfill Site F City of Burlington, Region of Halton

- Rowe, R. Kerry, October 1987 - Examination of the Potential Impact of Groundwater Quality of the Proposed Halton Landfill Site D Town of Milton, Region of Halton

- Walker, Wright Young Associates Limited, April 1984 - Consolidation Report, Phase II, Stage 2B - Selection of Candidate Sites

- Walker, Wright Young Associates Limited, November 1984 - Supplement to Stage 2B, Selection of Candidate Site Final Report

- Walker, Wright Young Associates Limited, October 1983 - Final Report, Phase II, Stage 2A - General Overview Analysis

- Walker, Wright Young Associates Limited, August 1983 - Final Evaluation Factors, Phase II, Stage 2A - General Overview Analysis

- Walker, Wright Young Associates Limited, January 1984 - Final Evaluation Factors, Phase II, Stage 2B - General Overview Analysis

- Walker, Wright Young Associates Limited, January 1987 - Comparative Analysis of Alternative Sites for Sanitary Landfilling, in the Regional Municipality of Halton - Site D & Site F

APPENDIX C

THE HYDROGEOLOGY OF THE IFGYL FORTY MILE AND OAKVILLE CREEK STUDY AREAS

Ontario

WATER RESOURCES
REPORT 5b

The Hydrogeology of the IFYGL Forty Mile and Oakville Creeks Study Areas

By
R. C. Ostry

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

Toronto Ontario

1979

GROUND WATER CONTRIBUTION TO LAKE ONTARIO

Another form of Darcy's Law, $Q = TIL$, was used to compute the amount of direct ground-water inflow to Lake Ontario, where:

- Q = quantity of water in Imperial gallons per day (Igpd)
- T = coefficient of transmissibility (Igpd/ft.)
- I = hydraulic gradient (feet per foot)
- L = width of cross section (feet).

In order that values be assigned for the parameters listed above, several assumptions on the ground-water flow field in the study areas were made. These assumptions with respect to contributing area, depth of active flow, saturated thickness, transmissibility and hydraulic gradient are discussed below.

Contributing Area

As indicated in an earlier section, the area near the Lake Ontario shore is considered to be in a general zone of ground-water discharge. In order to facilitate the computation of ground-water inflow to the lake, it was assumed that the area within a distance of two miles from the shore was representative of the conditions in this zone.

Depth of Active Flow

The mean value of bedrock penetration for 334 wells completed in the bedrock within the Oakville Creek study area was found to be 34 feet. A value of 27 feet for bedrock penetration was indicated for 53 bedrock wells in the Forty Mile Creek area. From the above data it was assumed that the mean value would reflect the practical limit of ground-water exploration for domestic supplies and therefore significant ground-water flow in the bedrock would not extend below 50 feet of bedrock penetration. This arbitary value of 50 feet of bedrock penetration is considered as the boundary between the active and stagnant parts of the ground-water reservoir.

Saturated Thickness

The static water level reported in the well records was used to determine the saturated thickness of the materials within a distance of two miles from the Lake Ontario shore in both study areas. In some wells (particularly in the Oakville area), a relatively low, static water level in conjunction with a thin overburden thickness indicated that the contribution of ground water from the overburden was negligible.

Transmissibility

Permeability values (table 7) were used to compute the transmissibilities of the materials within the contributing areas of interest. The various materials reported in all the logs of wells within a distance of two miles from the shore were assigned a permeability which was then multiplied by the saturated thickness to determine the overall transmissibility in the active part of the ground-water reservoir. For the few overburden wells in the study areas, an additional transmissibility for 50 feet of bedrock was added to their total. For the computations of the bedrock wells, it was assumed that all the wells penetrated the full thickness (50 feet of bedrock) of the active part of the ground-water reservoir. The total transmissibilities for each well were summed and the results are presented in Table 8. It was assumed that the transmissibility values of about 470 and 970 Igpd/ft. (Table 8) were representative for the areas along the north and south shores of Lake Ontario, respectively, in the hydrogeologic region under consideration.

Hydraulic Gradient

The average hydraulic gradient (I) was assumed to be 0.0123 (Map 5) for the study areas, as indicated in the earlier section on ground-water movement.

Computation of Ground Water Inflow

The values for T and I, as derived above, were substituted in the Darcy formula, Q = TIL to obtain a value of ground-water contribution to Lake Ontario, per mile length of shore line as follows:

Oakville Creek

Q = TIL

= 470 x 0.0123 x 5280

= 30,394 Igpd per mile length

= 0.057 cubic feet per second (cfs) per mile length

Forty Mile Creek

Q = TIL

= 970 x 0.0123 x 5280

= 62,866 Igpd per mile length

= 0.117 cubic feet per second (cfs) per mile length

TABLE 8. MEAN VALUES OF TRANSMISSIBILITY, DEPTH OF STATIC WATER LEVEL, OVERBURDEN THICKNESS AND BEDROCK PENETRATION FOR WELLS COMPLETED WITHIN TWO MILES OF THE LAKE ONTARIO SHORE IN THE IFYGL FORTY MILE AND OAKVILLE CREEKS STUDY AREAS

	Area	Number of wells	Mean overburden thickness (feet)	Mean static water level (feet below surface)	Mean transmissibility (Igpd/ft.)	Mean bedrock penetration (feet)
Wells completed in the overburden	Oakville	3	51 (41)	28 (24)	3075 (4442)	--
	Forty Mile	4	55 (10)	12 (3)	2416 (955)	--
Wells completed in the bedrock (G.B. Formation)	Oakville	26	9 (5)	8 (5)	465 (49)	34 (10)
Wells completed in the bedrock (Q Formation)	Oakville	42	11 (12)	14 (14)	288 (574)	44 (28)
	Forty Mile	55	23 (19)	10 (7)	863 (455)	27 (15)
All wells	Oakville	71			468 (1043)	40 (25)
	Forty Mile	59			968 (628)	27 (15)

(574) Standard deviation

It is assumed that these values of ground-water discharge for the study areas are representative of 32 and 44 miles along the north and south shores, respectively, of Lake Ontario. This region extends westwards from the mouth of the Humber River, near the western limits of the City of Toronto, around the western tip of Lake Ontario and then eastwards along the south shore of Lake Ontario to the Niagara River at the US-Canadian border (Figure 1). From the above, it is estimated that 1.8 and 5.2 cfs of ground water are discharging directly into Lake Ontario from the north and south shores, respectively. These values give a grand total of 7.0 cfs of ground-water discharge to Lake Ontario from the hydrogeologic region for which the Oakville and Forty Mile creeks are considered to be representative. This value is within the range of the values of 14.41 and 5.46 cfs for roughly the same area as computed by Haefeli (1972).